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Researches on Parameters Calculation of Designing Double-tuned Filter

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Abstract

Aiming at the question of parameter of double-tuned filter, A new method of designing double-tuned filter was proposed based on resonance frequency, by using the relationship that the impedance of double-tund filter and two parallel single tuned filters is equal and the resonance frequency of single tuned filter is the zero of the impedance of double-tuned filter. A simulation was established to prove the correctness of this method by using the software MATLAB in a power system. Simulation results show that the double-tuned filter designed in this method works well. All of this had an important guiding significance for the research of double-tuned filter.

Keywords: *Double-tuned filter, Impedance characteristics, Series resonance frequency, Parallel resonance frequency;*

1. Introduction

While power electronic devices getting a great improvement [1], the method of filtering harmonics are diverse [2, 3]. Passive filter has been widely used in filtering harmonics in power system by now, because it has a simple structure, low cost, high reliability, and so on. Usually, there are multiple frequency harmonics in a power system, so a group of parallel single tuned filters are needed to filter harmonics. This filtering method covers a large area and has a high cost. Double-tuned filter and two parallel single tuned filters have the same function that both of them can filter two different frequency harmonics. However, double-tuned filter has a lower cost than the two parallel single tuned filters [3].

Now, researches on double-tuned filter attract people's attention, such as loss [4], controllability [5, 6], parameters calculation [7, 8, 9]. Literature [7] firstly puts forward an algorithm about parameters calculation of double-tuned filter, but the operation process is complicated. Literature [8] is a new method on double-tuned filter parameters calculation, which was published four years ago. It needs to solve equations and contains a large amount of computation.

Aiming at parameters calculation of double-tuned filter, a new method is proposed based on resonance frequency. It does not need to solve equations, so it reduces the amounts of computation. The correctness of this method is proved in a power system simulation.

2. Working Principle of Double-tuned Filter

The conventional double-tuned filter is composed of series resonance circuit and parallel resonance circuit. The structure and frequency impedance characteristic curve of traditional double-tuned filter are shown in Figure 1.

Series resonance circuit (L_1、C_1) and parallel resonance circuit（L_2、C_2) respectively have resonance frequency ω_s and ω_p.They can be expressed as:

$$\begin{bmatrix} \omega_s \\ \omega_p \end{bmatrix} = \begin{bmatrix} 1/\sqrt{L_1 C_1} \\ 1/\sqrt{L_2 C_2} \end{bmatrix} \tag{1}$$

The impedance of double-tuned filter shown in Figure1 is

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$$Z = j\omega L_1 + \frac{1}{j\omega C_1} + (j\omega C_2 + \frac{1}{j\omega L_2})^{-1}$$
$$= \frac{(1-\frac{\omega^2}{\omega_s^2})(1-\frac{\omega^2}{\omega_p^2}) - \omega^2 L_2 C_1}{j\omega C_1(1-\frac{\omega^2}{\omega_p^2})} \quad (2)$$

where ω is the angular frequency in radians.

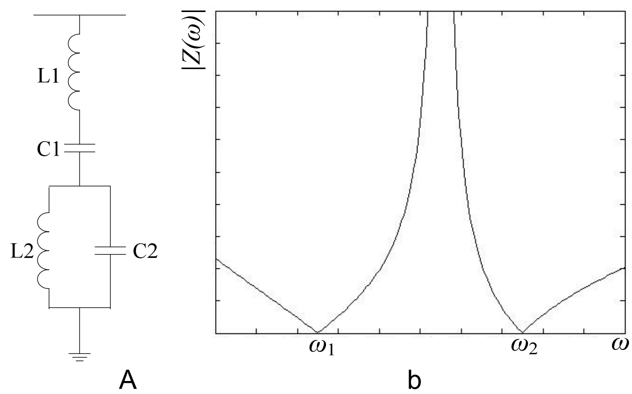

Figure 1. Double-tuned filter configuration and impendence -frequency characteristic curve

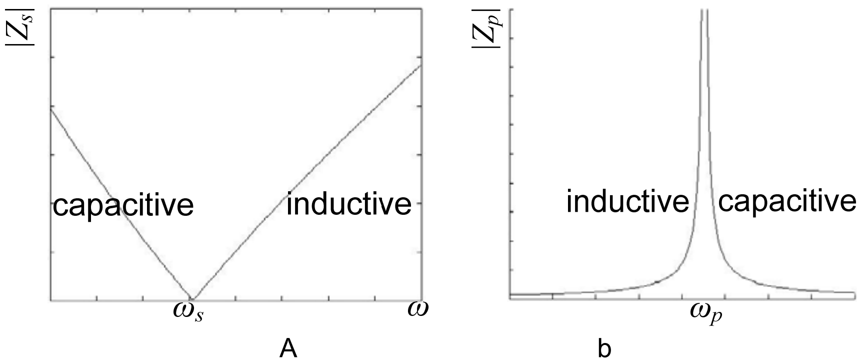

Figure 2. Impedance-frequency curve of series and parallel branch
a) Series resonance circuit impedance-frequency characteristic curve
b) Parallel resonance circuit impedance-frequency characteristic curve

The impedance of series resonance circuit can be expressed as $Z_s = j\omega L_1 + \frac{1}{j\omega C_1}$. Z_s has a zero ω_s. When $\omega<\omega_s$, the impedance is capacitive; when $\omega>\omega_s$, it is inductive. The impedance of parallel resonance circuit can be expressed as $Z_p = (j\omega C_2 + \frac{1}{j\omega L_2})^{-1}$. Z_p has a pole ω_p. when$\omega<\omega_p$, the impedance is inductive; when $\omega>\omega_p$, it is capacitive. Their frequency impedance characteristic curves are shown in Figure 2.

Picture b in Fig.1 shows the superimposed characteristic curves of series and parallel branch, from which, another two tuned frequency, ω_1 and ω_2 , can be seen clearly. At the two tuned frequencies, the total impedance of the filter is zero, so double-tuned filter can filter two different frequency harmonics.

3. The Parameters Calculation of Double-Tuned Filter

Two parallel single tuned filters are shown in Figure3. Their resonance frequencies respectively can be expressed as:

$$\begin{bmatrix} \omega_a \\ \omega_b \end{bmatrix} = \begin{bmatrix} 1/\sqrt{L_a C_a} \\ 1/\sqrt{L_b C_b} \end{bmatrix} \quad (3)$$

The impedance of two parallel single tuned filters can be expressed as:

$$Z_{ab} = ((j\omega L_a + \frac{1}{j\omega C_a})^{-1} + (j\omega L_b + \frac{1}{j\omega C_b})^{-1})^{-1}$$
$$= \frac{(1-\frac{\omega^2}{\omega_a^2})(1-\frac{\omega^2}{\omega_b^2})}{j\omega C_a(1-\frac{\omega^2}{\omega_b^2}) + j\omega C_b(1-\frac{\omega^2}{\omega_a^2})} \quad (4)$$

Two parallel single tuned filters and double-tuned filter are equivalent, so their impedance are equal,

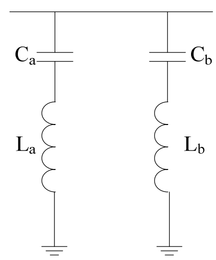

Figure 3. Parallel single tuned filter

$Z=Z_{ab}$. Z has two zeros: ω_a and ω_b. Formula (2) and (4) have the same constant term of 1, so their molecular and denominator are equal respectively.

First of all, a set is defined as $S=\{a,b\}$. After analyzing the coefficient of ω^4, we can gain an equation based on frequency, that is:

$$\omega_a \omega_b = \omega_s \omega_p \quad (5)$$

Analyzing the coefficient of ω,we can find out the equation of

$$C_1 = C_a + C_b = \sum_{i \in S} C_i \quad (6)$$

Analyzing the coefficient of ω^3, we can find out that

$$C_b \frac{1}{\omega_a^2} + C_a \frac{1}{\omega_b^2} = C_1 \frac{1}{\omega_p^2} \quad (7)$$

The parameter of L_1 can be calculated from (1)、(5)、(7) :

$$L_1 = \frac{1}{C_a\omega_a^2 + C_b\omega_b^2} = \frac{1}{\sum_{i\in S} C_i\omega_i^2} \quad (8)$$

Using L_1、C_1, we can calculate series resonance frequency ω_s and parallel resonance frequency ω_s , their frequencies can be obtained:

$$\omega_s = \frac{1}{\sqrt{L_1C_1}} \quad (9)$$

$$\omega_p = \frac{\omega_a\omega_b}{\omega_s} \quad (10)$$

Since ω_a is the zero of double-tuned filter impedance, so $Z(\omega_a)=0$. The equation to solve L_2 is as follow:

$$(1-\frac{\omega_a^2}{\omega_s^2})(1-\frac{\omega_a^2}{\omega_p^2}) - \omega_a^2 L_2 C_1 = 0 \quad (11)$$

Equation (11) can be simplified to get the value of L_2. And it is

$$L_2 = \frac{(1-\frac{\omega_a^2}{\omega_s^2})(1-\frac{\omega_a^2}{\omega_p^2})}{C_1\omega_a^2} \quad (12)$$

We also can solve L_2 by using ω_b. The two results are the same.
From (10)、(12), the value of C_2 can be obtained from the following equation:

$$C_2 = \frac{1}{L_2\omega_p^2} \quad (13)$$

All of these equations above are included in the new method, in which we only need parameters of capacitances in the two parallel single tuned filters to solve parameters calculation of the double-tuned filter.

4. Power System Simulation

In this paper, the software MATLAB is used to simulate the double-tuned filter designed in this new method. There is a plating base in which harmonics pollution is serious. We can prove the correctness of this method in this case. Plating power supply turns power frequency alternating current into pulse current. It contains the $6k\pm1$ odd harmonic component, such as six pulse converter's AC side, so it contains the $6k\pm1$ odd harmonic current. The simulative power system configuration and the parameters of the component in the system are respectively shown in Figure 4 and TABEL I.

When the double-tuned filter is not put into the system, the current in A phase is shown in Figure 5. Adopting FFT to analyze the current of A phase, the percent of the 5^{th} wave current and 7th wave current are separately 19.85% and 13.59%, so that 5th wave and 7th wave account for a large proportion in the system.

When the filter is put into operation, the current of A phase is shown in Figure 6, and the current in the double-tuned filter is shown in Figure 7.

In the Figure 6, the 5th and 7th wave are inhibited well in terms of the picture. After using FFT analysis, we can find out that the percent of 5th and 7th wave current are 1.38% and 0.74% separately. Figure 7 shows the 5th wave current and 7th wave current which the filter absorbs. In order to see the filtering effect clearly, the comparison of the percent of 5th and 7th harmonics is shown in table 2.

These figures that the simulation produced prove that 5th and 7th wave account for a large proportion before the double-tuned filter was put into operation. However, after the filter was put into operation, we found out that it had a good filtering effect.

Table 1. Component parameters in power system

Component	Parameter	Component	Parameter
AC1	110kV 50Hz 0°	L3	5mH
AC2	110kV 50Hz -120°	C3	500μF
AC3	110kV 50Hz -240°	R5	40Ω
R4, R6, R7	0.07Ω 108.28μH	L	3mH
C	40μF	R1	1000Ω
R3	100Ω	R	1Ω

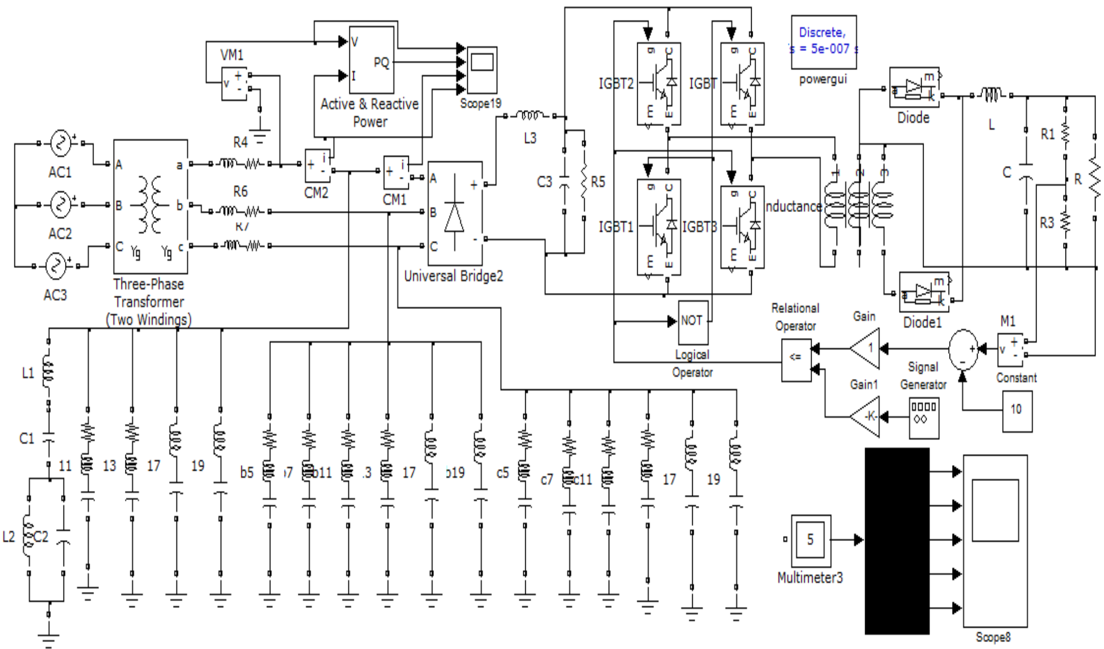

Figure 4. Simulative power system configuration

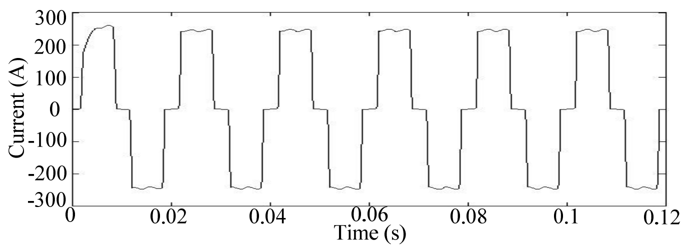

Figure 5. The current of A phase before filtering

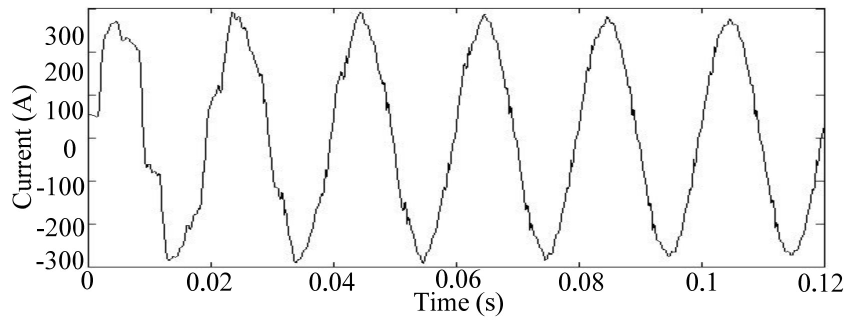

Figure 6. Current of A phase after filtering

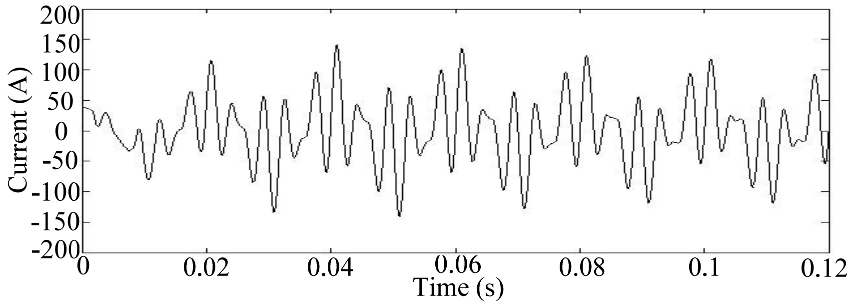

Figure 7. 5th and 7th wave in double-tuned filter.

Table 2. Comparison of the percent of 5th and 7th harmonics before and after filtering

	5th harmonic	7th harmonic
Before filtering	19.85%	13.59%
After filtering	1.38%	0.74%

5. Conclusion

This paper studies the parameters calculation of the double-tuned filter based on frequency and proposes a new idea in which we can get the parameters of double-tuned filter without solving equations, so it simplifies the operation. Double-tuned filter cost less than two parallel single tuned filters, so more economy will be produced. This new method has an important guiding significance for the research of double-tuned filter.

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