A New Algorithm for Designing the Parameter of Damped-Type Double Tuned Filter

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***Abstract*—Due to harmonics problems generated by converter devices. Currently, passive filter has been widely used in suppressing harmonics distortion. Passive filter which mostly used is double tuned filter. However, double tuned filter doesn't have a damping resistor which can prevent network elements from exposing to harsh condition such as when the system reactance and the filter impedance are conjugated, this condition can cause severe overvoltage harmonics on the filter and other power system components. There is a new configuration of double tuned filter that has damping resistor, called damped-type double tuned filter. Aiming at the question of parameter of damped-type double tuned filter, a new algorithm for designing the parameter of damped-type double tuned filter is proposed based on the relationship between impedance of two single tuned filter and one double tuned filter, and also based on the resonance at tuned frequency one and tuned frequency two are close to zero. Simulation result from MATLAB shows that the impedance of damped-type double tuned filter designed with this algorithm is appropriate. In addition, the simulation result from PSIM shows that damped-type double tuned filter designed with this algorithm works well.**

Keywords—harmonics, damped-type double tuned filter, filter design

I. INTRODUCTION

Harmonics distortion is not a new phenomenon in electrical power system, it is caused by non-linier devices in the power system such as converter [1]. HVDC Converter stations usually require ac/dc filters, the main purpose of which is to mitigate current or voltage distortion in the connected networks [2]. In addition, the ac side filters significantly compensate the network demanded reactive power [2]. Passive filter has been widely used in filtering harmonics in power system because it has simple structure, low cost, and high reliability. Double tuned filter is one of passive filters which mostly used. The main advantages of using double tuned over two parallel single tuned filter are double tuned filter has large covering area with one structure, occupies less space and needs only one switchgear, also double tuned filter has a lower cost than the two parallel single tuned filter [3] [4] [5].

Due to phenomenon network resonance takes place when power system reactance and the filter impedance are conjugated, it can cause severe overvoltage harmonics on the filter and other power system components, so last research proposed damping resistor to the conventional double tuned filter in different configuration. Literature [6] has previously put forward an algorithm about parameters calculation of damped-type double tuned filter, but the operation process is complicated and the characteristic curve impedance-frequency is not clearly differentiate between two resonant frequencies as shown in Figure 1.

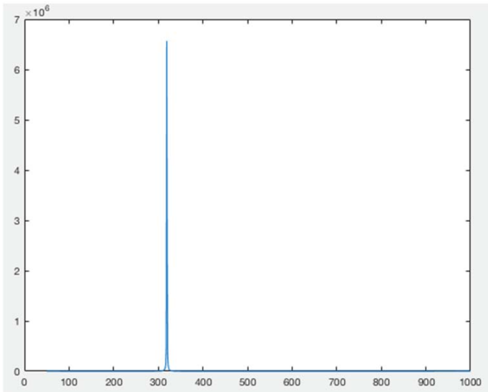

Figure 1. Impedance Response Damped-Type Double Tuned Filter due to impedance for Literature [6]

In order to calculate parameter of damped-type double tuned filter, a new algorithm for designing its parameter is proposed based on relationship impedance of two parallel single tuned filter and one double tuned filter, and also the resonance at the tuned frequency one and tuned frequency two are close to zero.

II. THE PARAMETER CALCULATION OF DOUBLE TUNED FILTER

There are so many configurations of damped-type double tuned filter as shown in Figure 2.

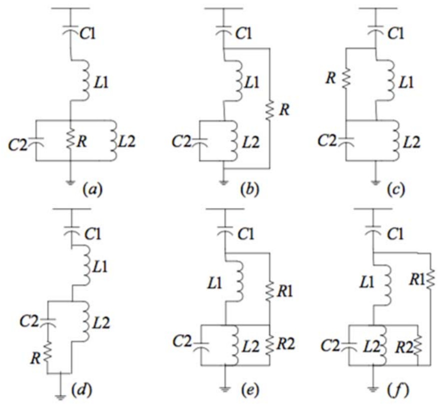

Figure 2. Configurations of damped-type double tuned filter

The most widely-used configuration of damped-type double tuned filter is shown in Figure 2 (a). From that figure, the first step is to express the relationship between two parallel single tuned filter as seen on Figure 3 and one conventional double tuned filter on Figure 4 into Equations. Then, place a damping resistor on the conventional double tuned filter as shown in Figure 5 and look for the parameter of resistor based on value of impedance at each resonance frequency is close to zero.

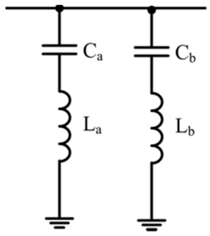

Figure 3. Configurations of two single tuned filter

Each single tuned filter has an impedance that can be expressed at Equation (1).

$$Z_s = j\omega L - j\frac{1}{\omega C} \quad (1)$$

At tuned frequency, Z_s will decrease to a minimum value. It can be assumed that Z_s will reach value at 0, so Equation (1) can be changed into Equation (2).

$$\omega L = \frac{1}{\omega C} \quad (2)$$

From Equation (2) above, resonance frequency for single tuned filter can be represented at Equation (3).

$$\omega = \frac{1}{\sqrt{LC}} \quad (3)$$

For two parallel single tuned filter as shown in Figure 3 that has two resonance frequencies, the Equation can be developed from Equation (3) and then can be expressed at Equation (4).

$$\begin{bmatrix}\omega_a \\ \omega_b\end{bmatrix} = \begin{bmatrix}1/\sqrt{L_a C_a} \\ 1/\sqrt{L_b C_b}\end{bmatrix} \quad (4)$$

The impedance Z_{ab} of two parallel single tuned filters as shown in Figure 3 above can be represented at Equation (5).

$$Z_{ab} = \left(\left(j\omega L_a - j\frac{1}{\omega C_a}\right)^{-1} + \left(j\omega L_b - j\frac{1}{\omega C_b}\right)^{-1}\right)^{-1}$$

$$= \frac{\left(1-\frac{\omega^2}{\omega_a{}^2}\right)\left(1-\frac{\omega^2}{\omega_b{}^2}\right)}{j\omega C_a\left(1-\frac{\omega^2}{\omega_b{}^2}\right) + j\omega C_b\left(1-\frac{\omega^2}{\omega_a{}^2}\right)} \quad (5)$$

The conventional double tuned filter consists of two capacitors and two inductors, which is composed by series resonance circuit (L_1, C_1) and parallel resonance circuit (L_2, C_2).

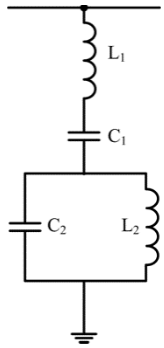

Figure 4. Configurations of conventional double tuned filter

Calculation of series resonance frequency and parallel resonance frequency of conventional double tuned filter can be expressed at Equation (6).

$$\begin{bmatrix}\omega_s \\ \omega_p\end{bmatrix} = \begin{bmatrix}1/\sqrt{L_1 C_1} \\ 1/\sqrt{L_2 C_2}\end{bmatrix} \quad (6)$$

From Figure 4, the impedance Z_f of conventional double tuned filter can be represented at Equation 7.

$$Z_f = j\omega L_1 + \frac{1}{j\omega C_1} + \left(j\omega C_2 - j\frac{1}{\omega L_2}\right)^{-1}$$

$$= \frac{\left(1-\frac{\omega^2}{\omega_s{}^2}\right)\left(1-\frac{\omega^2}{\omega_p{}^2}\right) - \omega^2 L_2 C_1}{j\omega C_1\left(1-\frac{\omega^2}{\omega_p{}^2}\right)} \quad (7)$$

Literature [7] has proposed a method for calculating the parameter of the conventional double tuned filter. The impedance between two single tuned filter at Equation (5) and the conventional double tuned filter at Equation (7) are equivalent. Analyzing the coefficient of ω, the parameter of C_1 can be calculated by using Equation (8).

$$C_1 = C_a + C_b \quad (8)$$

The parameter of L_1 can be calculated by using Equation (9).

$$L_1 = \frac{1}{C_a\omega_a{}^2 + C_b\omega_b{}^2} \quad (9)$$

Then, the parameter of L_2 can be calculated by using Equation (10).

$$L_2 = \frac{\left(1-\frac{\omega_a{}^2}{\omega_s{}^2}\right)\left(1-\frac{\omega_a{}^2}{\omega_p{}^2}\right)}{C_1\omega_a{}^2} \quad (10)$$

The parameter of C_2 can be found by using Equation (11).

$$C_2 = \frac{1}{L_2\omega_p{}^2} \quad (11)$$

where ω_s and ω_p can be calculated by using Equation (12) and Equation (13) respectively.

$$\omega_s = \frac{1}{\sqrt{L_1 C_1}} \quad (12)$$

$$\omega_p = \frac{\omega_a \omega_b}{\omega_s} \tag{13}$$

On the other hand, by analyzing the capacitance of two parallel single tuned filter and parallel resonance frequency of conventional double tuned filter, this paper proposes the calculation of the parameter of L_1 by using Equation (14).

$$L_1 = \frac{1}{C_1({\omega_a}^2 + {\omega_b}^2)/2} \tag{14}$$

where the parameter of C_1can be calculated by using Equation (15).

$$C_1 = \frac{MVAR}{kV^2\omega} \tag{15}$$

which ω is the fundamental frequency. The two results from Equation (8) and Equation (15) are the same, also the two results of Equation (9) and (14) are the same. By using Equation (14) and (15) the calculation to get the parameter of C_1 and L_1 is simpler rather than calculating capacitance for each resonance frequency from two parallel single tuned filter firstly.

III. THE PARAMETER CALCULATION OF DAMPED-TYPE DOUBLE TUNED FILTER

In order to prevent network elements from exposing severe overvoltage, damping resistor is added to the conventional double tuned filter as shown in Figure 5.

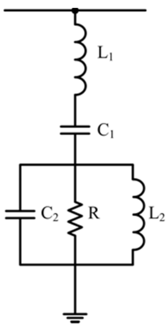

Figure 5. Configurations of conventional double tuned filter

This paper developes impedance of damped-type double tuned filter based on Figure 5, the impedance can be represented at Equation (16).

$$Z_f = j(\omega L_1 - \frac{1}{\omega C_1}) + \left(\frac{1}{j\omega L_2} - \frac{1}{j\,{}^{1}\!/_{\omega C_2}} + \frac{1}{R}\right)^{-1}$$

$$= \sqrt{\left(\frac{\frac{{L_2}^2 R}{{C_2}^2}}{\frac{{L_2}^2}{{C_2}^2} + \left(\omega L_2 R - {}^{R}\!/_{\omega C_2}\right)^2}\right)^2 + \left(\omega L_1 - \left(\frac{\frac{L_2 R}{C_2}\left(\omega L_2 R - {}^{R}\!/_{\omega C_2}\right)}{\frac{{L_2}^2}{{C_2}^2} + \left(\omega L_2 R - {}^{R}\!/_{\omega C_2}\right)^2}\right) - \frac{1}{\omega C_1}\right)} \tag{16}$$

The analysis of impedance frequency characteristic curve from Equation (16) has been done using MATLAB and has been plotted as shown in Figure 6.

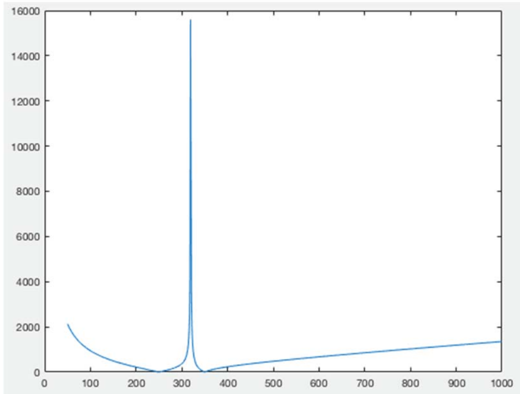

Figure 6. Impedance-frequency Characteristic Curve of New Developing Impedance Damped-type Double Tuned Filter

From Figure 6 above, the characteristic curve between impedance and frequency is clearly different, compared with the impedance from literature [6] shown in Figure 1. Figure 6 shows clearly the resonance frequency at tuned frequency one (ω_1) and tuned frequency two (ω_2) are close to zero because it is suppressed by filter, and the impedance at parallel resonance is too high.

By using the value approach of the resonance frequency at tuned frequency one (ω_1) and tuned frequency two (ω_2) are close to zero, this paper proposed a new algorithm to find out the parameter of damping resistor (R) of the damped-type double tuned filter as shown in Figure 7.

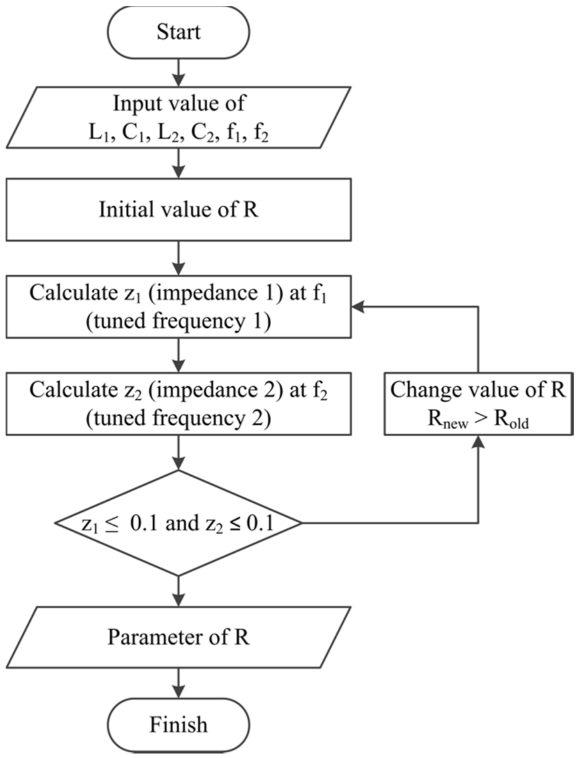

Figure 7. A new Algorithm to find out parameter of damping resistor (R) of damped-type double tuned filter

In conclusion, when the voltage in the network (kV) and demanded reactive power in the network (MVAR) are known, as well as, tuned frequency one (f_1), tuned frequency two (f_2), series resonance frequency (ω_s), parallel resonance frequency (ω_p) are determined, then the parameter of the damped-type double tuned filter (C_1, L_1) and (C_2, L_2) can be calculated by using Equation (15, 14) and Equation (11,10) respectively. For the parameter of damping resistor (R), it can be calculated by using an algorithm shown in Figure 7.

For quick calculation of the parameter of damping resistor (R), with the impedance of damped-type double tuned filter at Equation (16), an algorithm as shown in Figure 7 can be written in a language program using MATLAB below:

```
for r=1:1000000

Imp1=sqrt((((l2*l2*r/(c2*c2))/((l2*l2/(c2*c2))+(((2*pi*fre1*l
2*r)-(r/(2*pi*fre1*c2)))*((2*pi*fre1*l2*r)-(r/(2*pi*fre1*c2
))))))*((l2*l2*r/(c2*c2))/((l2*l2/(c2*c2))+(((2*pi*fre1*l2*r)-
(r/(2*pi*fre1*c2)))*((2*pi*fre1*l2*r)-(r/(2*pi*fre1*c2))))))
+(((2*pi*fre1*l1)-(1/(2*pi*fre1*c1))-((((l2*r)/c2)*(2*pi*fre1
*l2*r-(r/(2*pi*fre1*c2))))/((l2*l2/(c2*c2))+((2*pi*fre1*l2*r-
(r/(2*pi*fre1*c2)))*(2*pi*fre1*l2*r-(r/(2*pi*fre1*c2)))))))*
((2*pi*fre1*l1)-(1/(2*pi*fre1*c1))-((((l2*r)/c2)*(2*pi*fre1*
l2*r-(r/(2*pi*fre1*c2))))/((l2*l2/(c2*c2))+((2*pi*fre1*l2*r-
(r/(2*pi*fre1*c2)))*(2*pi*fre1*l2*r-(r/(2*pi*fre1*c2)))))))));

Imp2=sqrt((((l2*l2*r/(c2*c2))/((l2*l2/(c2*c2))+(((2*pi*fre2*l
2*r)-(r/(2*pi*fre2*c2)))*((2*pi*fre2*l2*r)-(r/(2*pi*fre2*c2
))))))*((l2*l2*r/(c2*c2))/((l2*l2/(c2*c2))+(((2*pi*fre2*l2*r)-
(r/(2*pi*fre2*c2)))*((2*pi*fre2*l2*r)-(r/(2*pi*fre2*c2))))))
+(((2*pi*fre2*l1)-(1/(2*pi*fre2*c1))-((((l2*r)/c2)*(2*pi*fre2
*l2*r-(r/(2*pi*fre2*c2))))/((l2*l2/(c2*c2))+((2*pi*fre2*l2*r-
(r/(2*pi*fre2*c2)))*(2*pi*fre2*l2*r-(r/(2*pi*fre2*c2)))))))*
((2*pi*fre2*l1)-(1/(2*pi*fre2*c1))-((((l2*r)/c2)*(2*pi*fre2*
l2*r-(r/(2*pi*fre2*c2))))/((l2*l2/(c2*c2))+((2*pi*fre2*l2*r-
(r/(2*pi*fre2*c2)))*(2*pi*fre2*l2*r-(r/(2*pi*fre2*c2)))))))));

  if (Imp1 <= 0.1 && Imp2 <= 0.1)
    fprintf('The parameter of Damping Resistor (R) is %d \n',
r);
    break
  end
end
```

IV. Simulation of Power System with Damped-Type Double Tuned Filter

This paper uses software PSIM to simulate the damped-type double tuned filter designed with this new algorithm. PSIM is one of many software programs to simulate power electronics and power system. The configuration of power system consists of generator, transformer, conductor, six pulse converters, load and some measurement devices. Six pulse converters will raise the harmonic order following Equation (14). Figure 8 shows the power system which has installed damped-type double tuned filter. The parameter of the configuration in Figure 8 before filtering is shown in Table 1.

$$n = kp \pm 1 \qquad (14)$$

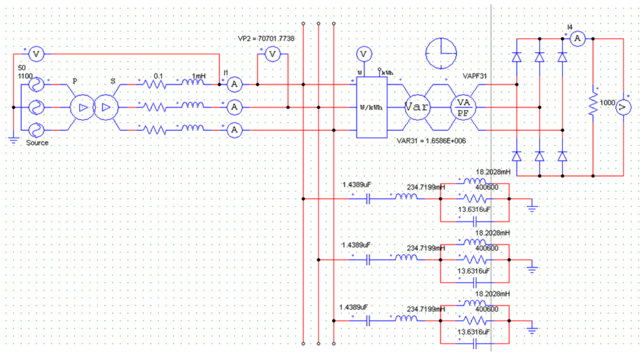

Figure 8. Configuration of Power System

TABLE I. Parameter of The Configuration of Power System

Parameter	Value
U	110kV
F	50Hz
P	20.808.519,00Watt
Pf Existing	0,9552
Pf Target	0,9999

Six pulse converter in this simulation raises the order 5th, 7 th, 11st, 13rd, 17th, 19th, and so on. When the damped type filter is not installed in power system, the current that measured by amperemeter 1 at Phase 1 is shown in Figure 9. PSIM provides FFT function that enables engineer to convert time function into frequency function to analyze each component of harmonics. From Figure 10, it can be seen and measured the harmonic distortion for each component. Most harmonics distortions occur at 5th order and 7th order, which has value 25,1563A and 10,7881A respectively.

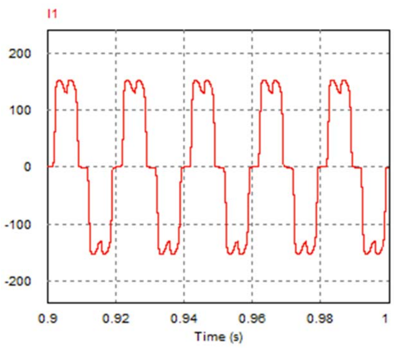

Figure 9. The Waveform Current Phase 1 before Filtering

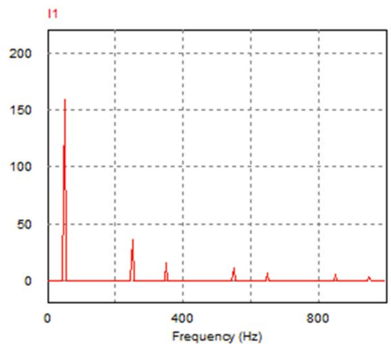

Figure 10. The Harmonic Distortion per Order at Phase 1 before Filtering

The required parameter of damped-type double tuned filter for the power system according to the new algorithm is proposed in this paper as shown in Table 2.

TABLE II. PARAMETER OF THE FILTER

Parameter	Value
C1	1,4389uF
L1	234,7199mH
C2	13,6316uF
L2	18,2028mH
R	400.600ohm

When the damped-type double tuned filter is installed in power system, the current waveform at Phase 1 is shown in Figure 11. Damped-type double tuned filter is designed suppress harmonic 5^{th} order and 7^{th} order. Then, in Figure 12 shows that the filter effectively works, harmonic 5^{th} order and 7^{th} order has been suppressed become 0,0036A and 0,0083A respectively.

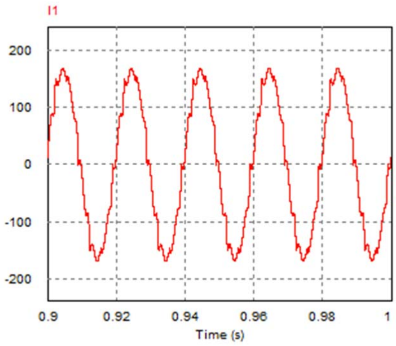

Figure 11. The Waveform Current Phase 1 after Filtering

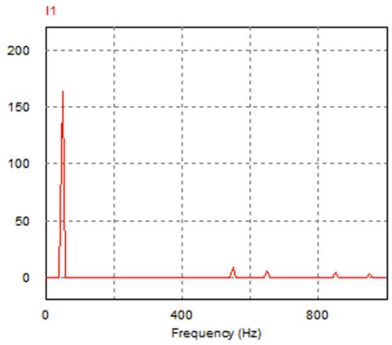

Figure 12. The Harmonic Distortion per Order at Phase 1 after Filtering

In order to summarize the simulation, Figure 11 shows the current waveform after filtering, the form is close to sinusoidal compared with Figure 9 the current waveform before filtering. Then, Figure 12 shows that after damped-type double tuned filter designed with new algorithm proposed in this paper is installed in power system, at 5th order and 7th order harmonics content are close to zero compare with Figure 10 before filtering. However, after the filter is installed into power system, it is proven that a new algorithm works well and has a good filtering effect.

V. CONCLUSION

This paper explores the calculation of parameter of the damped-type double tuned filter based on the relationship impedance of two parallel single tuned filter and one double tuned filter, and also the resonance at the tuned frequency one and tuned frequency two are close to zero. The calculation is very simple and the algorithm for calculating the damping resistor can be figured out by making a language program on MATLAB. This paper suggests a new equation of impedance of the damped-type double tuned filter which can be used to give an input for literature [6]. The new impedance and new algorithm proposed in this paper have been proved by simulation using MATLAB and PSIM software and it works splendidly.

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