A New Control Circuit for Series Active Filters to Eliminate Voltage Flicker and Harmonics

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Abstract: *This paper presents a new control structure for the series active filters. In this controlling structure, resonant controllers are used in order to eliminate harmonics and voltage flicker. The presented control circuit has the property of selective harmonics elimination and voltage flicker. Via this feature it is possible to separate selected harmonics in the point of common coupling voltage and then eliminate them by making reference voltage. The unique capability of this series active filter is the elimination of voltage flicker in the point of common coupling. It has been created by using the resonant controller. The series active filter is simulated in a typical network and the results shows that this filter reduces the harmonics and eliminates voltage flicker.*

Keywords: Voltage flicker, Series active filter, Power quality, Voltage harmonics.

1. Introduction

In recent years, with rapid growth of industries and increasing consumption of electrical energy and due to the variety among electrical loads, the power quality in power systems has become increasingly important [1].

The main challenging factors in power quality are harmonics and voltage flicker. Harmonics are produced by nonlinear loads and voltage flicker is produced by electric arc furnaces [2].Harmonics cause communication interferences, resonance and hotness in transformers. On the other hand, voltage flicker can cause a significant and annoying change in the light of lamps and can lead to malfunctions in some electronic equipment [3]. Researches show that just 0.5% of amplitude changes with frequency range 2 to 10 Hz can bother eyes [4, 5]. And so reduction and elimination of these effects is essential.

Among proposed methods, active filters are one of the methods to eliminate harmonics [6].Series active filter is a kind of active filters. This equipment was introduced in the 1980s decade and generally used to improve the voltage waveform and in fact it is a harmonic isolator between nonlinear load and power supply [7].

Some kinds of instruments such as SVC and STATCOM have been introduced to reduce voltage flicker but these devices are too expensive [8].

Nowadays, researchers have paid attention to those kinds of devices which are able to improve various aspects of power quality at one time [9].

In this paper, it is introduced a new control circuit, which is series active filter and it is able to eliminate voltage flicker at the point of common coupling (PCC) beside its main task that is eliminating voltage harmonics.

To confirm the correctness of operation of presented control circuit, its model has been simulated on a network and its good performance has been shown.

At fallowing and in the section 2, system structure including power circuit and control circuit are described. In the section 3, simulation results have been shown. In the section 4, conclusion is presented.

2. System's Structure

Series active filters have two main parts; power circuit and control circuit, which will be described in the next subsections.

2.1 Power Circuit

Fig. 1 shows a general scheme of series active filter.

In Fig. 1, nonlinear load is a three phase rectifier load with no neutral connection. Load current does not have even harmonics and triples and just gives 6n+1, n=1, 2, … harmonic orders. K_+=6n+1 harmonics are positive sequence and k_-=6n-1 are negative sequence. Flowing nonlinear load current harmonics from series impedance (L) causes voltage harmonics in PCC.

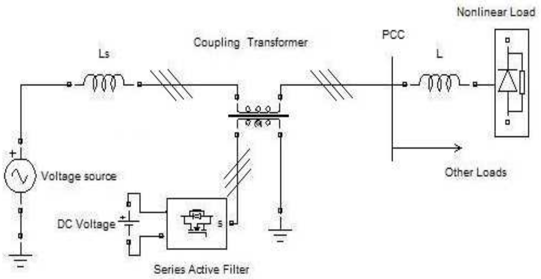

Fig. 1: General profile of series power active filter

On the other hand, source side has voltage flicker and makes PCC voltage to have flicker. Power circuit of series active filter is included of a six pulse switch and a three phase's transformer which is used as coupling transformer [10].

2.2 Control Circuit

Via measuring harmonic voltages and transferring these voltages from abc axes to dq0 axes and by using a 4th orders high pass filter, voltage harmonics get separate of main component. Main component appears in the form of dc current in dq0 axes.

To get ω_e, angular speed of reference frame and Θ_e, initial phase, it is used a PLL.

2.2.1 Control circuit of harmonic section

Voltage harmonics' control circuit is divided to different sections which are assigned for every pair of harmonics with k=6n±1 orders.

As every part of controlling sections operates in reference synchronous frame, it is possible to change every pair of harmonics with k=6n±1 orders to k=6n orders and then just one controller with desired frequency will be enough for every pair of harmonics.

Suppose that active filter has L_F inductance and R_F resistance, and V_F, filter voltage, V_T, coupling transformer's terminal voltage, i_F, filter current and superscript k shows harmonics' order in reference synchronous frame. Then we have:

$$\underline{v_F^k} - \underline{v_T^k} = R_F \underline{i_F^k} + L_F \frac{d\underline{i_F^k}}{dt} + jk\omega_e L_F \underline{i_F^k} \,. \tag{1}$$

This system has a complex pole at $-\dfrac{R_F}{L_F} + j\omega_e$ point in which positive ω_e is for positive sequence harmonics and negative ω_e is for negative sequence harmonics.

For designing this controller, it is used pole and zero cancelation method for $k\omega_e$ harmonic. For this purpose H_{PIk}^k used in the following way

$$H_{PIk}^k = K_{pk} + (K_{ik} + jk\omega_e K_{pk})\frac{1}{s} \tag{2}$$

K=6n±1 harmonics are our aim harmonics. By converting these harmonics to reference synchronous frame with – $k\omega_e$ frequency shift for positive sequence harmonics and $+k\omega_e$ for negative sequence harmonics (which is k=6n). We can get transfer function H_{PIk^+} for positive sequence harmonics and H_{PIk^-} for negative sequence harmonics.

$$H_{PIk^+} = \frac{K_{pk}s + K_{ik}}{s - jk\omega_e}$$
$$H_{PIk^-} = \frac{K_{pk}s + K_{ik}}{s + jk\omega_e} \tag{3}$$

To calculate H_{PIk}^k, we must at first calculate the sum of H_{PIk^+} and H_{PIk^-}.

$$H_{PIk} = H_{PIk^+} + H_{PIk^-} = 2\frac{K_{pk}s^2 + K_{ik}s}{s^2 + (k\omega_e)^2} \tag{4}$$

Transfer function of H_{PIk} is a resonant controller with real coefficients which gives zero gain to dc signal.

With assumption of ideal PWM, its closed loop transfer function will be as follow:

$$H_k = \frac{\underline{v_{Fk}}}{\underline{\overset{*}{v}_{Fk}}} = \frac{2(K_{pk}s^2 + K_{ik}s)}{L_F s^3 + (2K_{pk} + R_F)s^2 + [2K_{ik} + L_F(k\omega_e)^2]s + R_F(k\omega_e)^2} \tag{5}$$

In which v_{Fk} is output voltage of filter and $\overset{*}{v}_{Fk}$ is the measured voltage in PCC. Fig.2 shows the frequency response of Eq. (5) and is drawn for K_{pk}=1, K_{pk}=5.As it is obvious, for each K_{pk}, amplitude of H_k in 300 Hz frequency equals one and its phase is zero.

In order to eliminate zero of controller and pole of RL model, we must have $\frac{k_{ik}}{k_{pk}} = \frac{R_F}{L_F}$, in which K_{pk} value is chosen by designer [11]. The calculated transfer function is used as a second orders band pass filter for $k\omega_e$ frequency.

$$H_k = \frac{\underline{v_{Fk}}}{\underline{\overset{*}{v}_{Fk}}} = \frac{2K_{pk}s}{Ls^2 + 2K_{pk}s + L(k\omega_e)^2} \tag{6}$$

By analyzing Bode diagram, we can show that with having a positive K_{pk}, this transfer function is always stable.

Fig.3 shows the accurate correlation between Eq. (5) and Eq. (6) and in fact by eliminating zero and pole, the transfer function H_k in Eq.(6) will have the same frequency response like Eq.(5).

In general, voltage harmonic controller can be achieved by superposition of H_{pIk} for every pair of harmonics:

$$H_{PI} = \sum_{n=1}^{6} 2\frac{K_{pk}s^2 + K_{ik}s}{s^2 + (k\omega_e)^2}, k = 6n \tag{7}$$

When the system has the some pairs of harmonics with high amplitude, we can raise the active filter's ability in response to these harmonics via eliminating of other resonant controllers.

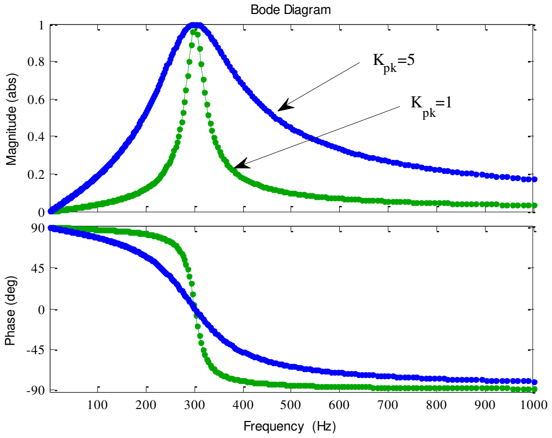

Fig. 2: The frequency response of Eq. (5)'s transfer function

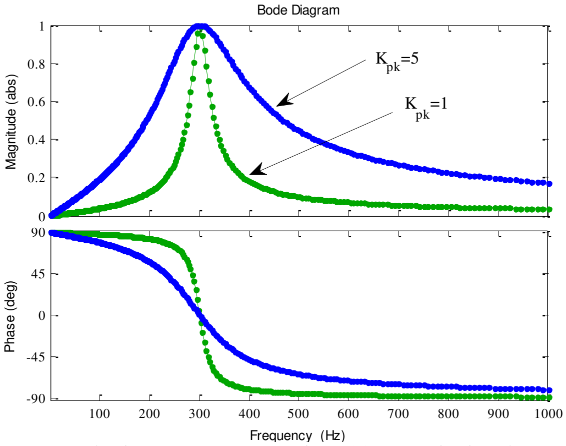

Fig. 3: The frequency response of Eq. (6)'s transfer function

2.2.2 Control circuit of flicker

In this section, we make use of a transfer function which is same as control circuit of harmonic part. In this part, we set the frequency in which transfer function has amplitude one on 10 Hz. Of course like harmonic part, we can use some parallel transfer functions for eliminating flicker in other frequencies.

Suppose that the superscript **u** is a non-integer digit and it shows the ratio of flicker frequency to main frequency of system. So the transfer function of control circuit of flicker part will be as follow:

$$H_k=\frac{v_{Fk}}{\underline{v^*_{Fk}}}=\frac{0.01\times u\omega_e s}{s^2+0.01\times u\omega_e s+(u\omega_e)^2} \qquad (8)$$

Fig.4 is frequency response of transfer function (8).

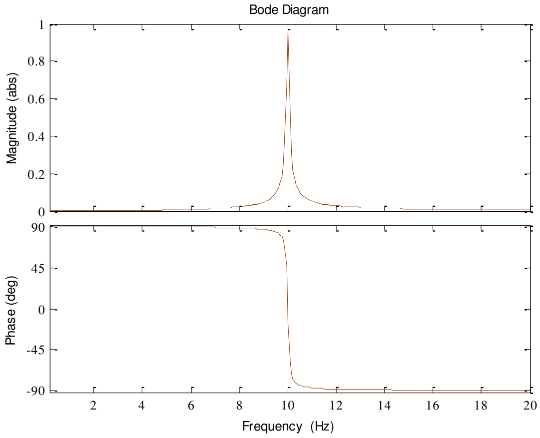

Fig.4: The frequency response of Eq. (8)'s transfer function

3. Simulation Results

In this section, the proposed controller is simulated on a typical power system in Fig.1. Fig.5 shows the PCC voltage waveform and harmonics amplitude percent (to amplitude of main component) before applying series active filter. As it is seen, THD of voltage is 8.93%.

Fig.6 shows PCC voltage waveform after applying series active filter and it is obvious that THD of voltage has decreased to 1.96%.

For showing the effect of series active filter on voltage flicker, it is supposed that source has a voltage flicker with 0.5% amplitude and 10 Hz frequency. Fig.7 shows the source's voltage waveform which has flicker.

Operation of series active filter in order to prevent the entrance of these PCC voltage flickers is shown in Fig.8 which shows the efficient performance of series active filter in preventing entrance of voltage flicker to PCC.

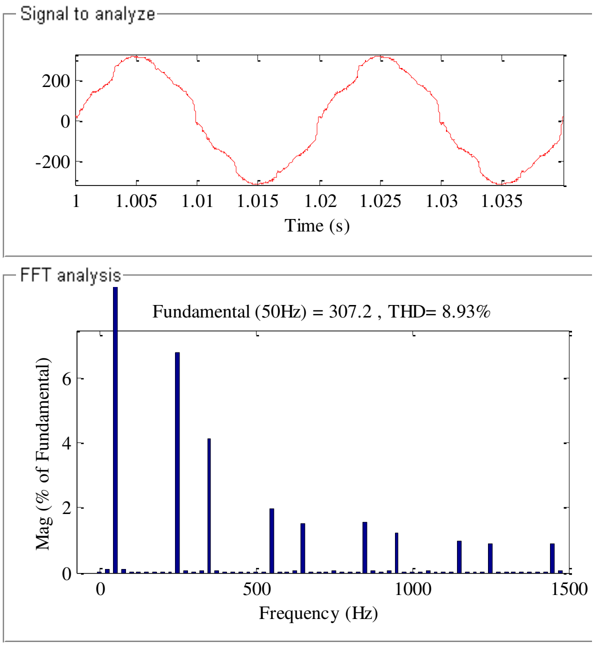

Fig.5: The PCC voltage waveform before applying series active filter

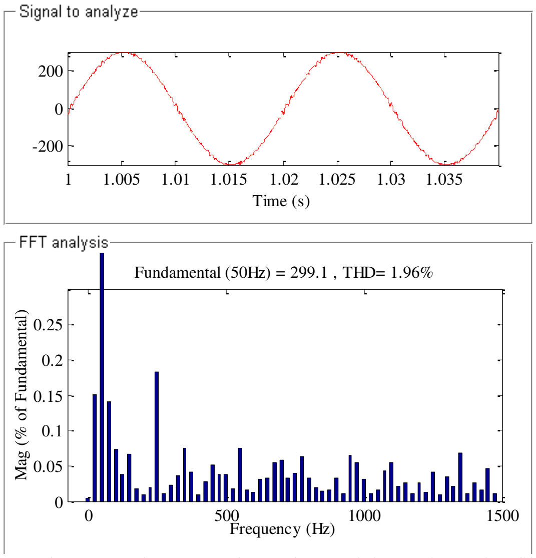

Fig.6: The PCC voltage waveform after applying series active filter

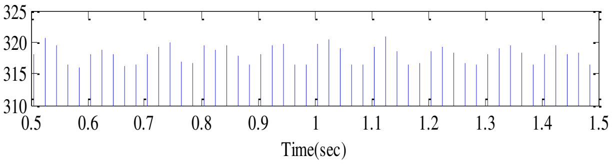

Fig.7: The source's voltage with flicker before applying series active filter

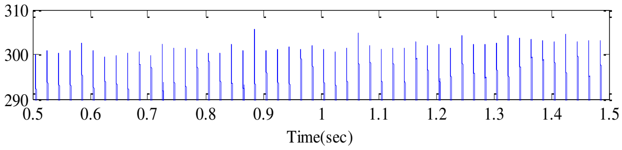

Fig.8: The PCC voltage without flicker after applying series active filter

4. Conclusion

In this paper a new controlling algorithm for series active filter has been presented. By this control circuit, it is possible to eliminate PCC voltage flicker and harmonics. Results of simulation prove the efficiency of this algorithm.

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