

Different control strategies applied to series active filters

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Abstract. The series active filters are used to compensate loads of the kind voltage harmonics source. In this paper three different control strategies have been applied to a series active filter. The first is based on that the filter voltage must be proportional to the harmonic of the source current. With the second strategy the filter voltage must be equal to voltage harmonics on the side load but in opposition. The third strategy is a hybrid control where the filter voltage is obtained using both previous strategies. The proposed control approaches have been analyzed and the simulation results using Matlab-Simulink have been presented.

Key words

Series active filters, harmonics, distorted voltage.

1. Introduction

Many social and economic activities depend on electrical energy quality and its efficiency. Both industrial and commercial users are interested in guaranteeing the quality signal which feed their different systems. To reach this aim it requires mitigating the current harmonics or voltage harmonics which are generated by the load.

Effective compensation is related with the load type [1], therefore, a necessary topic will be to define the topology and control strategy appropriate to each specific load. The shunt active power filters have limitations to compensate harmonics of some load types [2], such as loads of voltage harmonics source. A topology more suitable to these load types is the power filters of connection series.

A series power electronic converter can be used to eliminate disturbances and unbalances of the network voltage with linear loads; in this way, it performs as Dynamic Voltage Restorer (DVR) [3]. On the other hand,

this configuration can be also used as series active filter. The series active power filter generates the appropriate waveforms to mitigate voltage harmonics injected by the load; it works then as a harmonic filter.

Different control strategies have been proposed to the power filters of connection series [6]. These let obtain the control signal to the switching of the electronic power devices of the active filter. One of them is to generate a proportional voltage to the harmonic of the source current [4,5,6]. From the point of view theoretical, a value infinite of the constant should be the ideal situation; however, it should suppose a control objective impossible to reach, therefore, a small value k is chosen to avoid instabilities in the system and active filters of reasonable rated power. However, the choice of the appropriate value of k is a non solved question due to it is related with the value of the accompanying passive filter and the source impedance.

Another proposed control technique is based in that the compensator generates a voltage waveform similar to the voltage harmonic in the side load but in opposition, but its compensation features depend on the measurement error, [7].

A further control strategy is possible: combining both previous. Here, after to study the two first strategies, a hybrid approach to improve the compensation characteristics has been proposed.

In this work, three control strategies have been analyzed to use a series active filter as a harmonic filter. The simulation results using Matlab-Simulink have been presented

2. Topology

The active power filter designed consists of a three-phase PWM voltage source inverter, which is connected in series with the ac source impedance and load, through

three single phase transformers (Fig. 1). A small rate passive filter to suppress switching ripples is connected between the transformers and the inverter.

The series active filter consists of three parts, namely, the control circuit for generating the reference compensation voltage, the voltage control circuit of PWM inverter including PWM signal generating and power semiconductor gate drive circuit and PWM inverter main circuit.

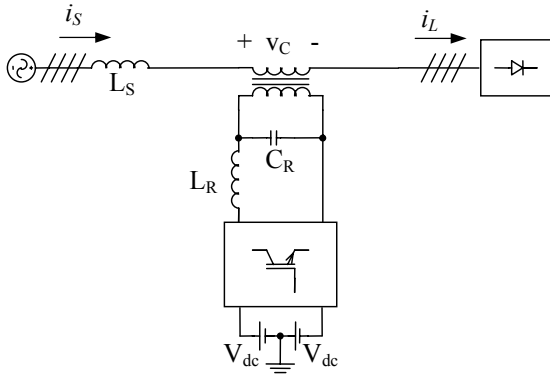


Fig. 1. Scheme of active filter connected in series to the source

The load to compensate is composed by three single phase non-controlled rectifiers, each of them connected between phase and neutral. On the dc side a large capacitor is connected (voltage type harmonics-producing load).

3. Control strategies analyzed

Using the topology shown in Fig. 1, three different strategies will be analyzed for the control of the series active filter:

- Strategy 1. The filter voltage is proportional to the harmonic of the source current.
- Strategy 2. The filter voltage is equal to voltage harmonics on the side load but in opposition.
- Strategy 3. The filter voltage is obtained using both previous strategies.

A. Strategy 1

The first strategy consists in generating a voltage proportional to the source current harmonics, that is

$$v_{CH} = k i_{SH} \quad (1)$$

Where, k is a constant and i_{sh} the source current harmonics different from the fundamental. With this control the active filter can be regarded as a resistor, whose the resistance is zero to the fundamental component while it is k ohms to the harmonic component.

To analyze the behaviour of the circuit, the single equivalent circuit shown in Fig. 2 will be used. This circuit is defined for the harmonics present in the system except for the fundamental. In Fig. 2, V_{SH} denotes the

source voltage harmonics; Z_S is the source impedance; V_{CH} the series active filter voltage; V_{LH} the load voltage harmonics; V_{CCH} the common coupling point voltage and I_{SH} the system current.

The common coupling point voltage for the n th-harmonic can be obtained in phasor form

$$V_{CCHn} = \frac{k}{(Z_{Sn} + k)} V_{SHn} + \frac{Z_{Sn}}{(Z_{Sn} + k)} V_{LHn} \quad (2)$$

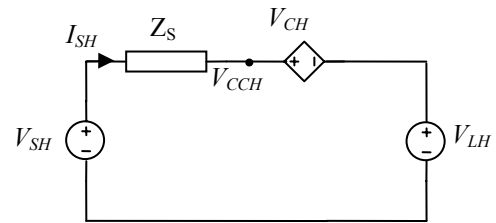


Fig. 2. Equivalent single circuit

When $k \rightarrow \infty$, then $V_{CCHn} = V_{SHn}$. Under that condition, there is not distortion in the side source voltage by the harmonics load.

The compensation features are influenced by the value of k . The choice of a suitable value of k is very difficult. The larger k is the better to compensate harmonics; however, it can not be too large to ensure system stability. This is the weak point of the control method.

B. Strategy 2

The aim of the second strategy has been to generate a voltage proportional to the load voltage harmonics but in opposition. That is

$$v_{CH} = -v_{LH} \quad (3)$$

From Fig. 2 it can be found that regarding the n th-order harmonic the common coupling point voltage is null. So the aim of harmonic compensation can be realized. However, the control depends on the detection precision of harmonic voltage and the control precision of PWM inverter. Therefore, there is an error in the measurement of the V_{LH} and an error in the signal generate by the inverter. Considering k_v as the error in the signal generated by the active filter, the common coupling point voltage to the n th-order harmonic is

$$V_{CCHn} = V_{LHn}(1 - k_v) \quad (4)$$

There is not distortion in the side source voltage by the harmonics load when $k_v=1$ although, this is a aim impossible to reach.

C. Strategy 3

The third strategy combines the two previous control approaches. The active filter generates a voltage

$$v_{CHn} = k i_{SHn} - k_v v_{LHn} \quad (5)$$

According to Fig. 2 the common coupling point voltage for the nth-order harmonic in phasor form is

$$V_{CCHn} = \frac{k}{(Z_{Sn} + k)} V_{SHn} + \frac{Z_{Sn}(1 - k_v)}{(Z_{Sn} + k)} V_{LHn} \quad (6)$$

This control let improve the waveform of the voltage respect from the previous strategies because it reduces the influence of the error in the signal generated by the active filter, it is due to the term $(1 - k_v)V_{LHn}$ in expression (6) is divided by k .

In this way the constant k can be lower that in the first strategy. This value can be chosen to ensure the stability of the system.

In views of this, when the series active filter employs the hybrid control approach, its compensation performance should be better that the two control approach previously discussed.

4. System configuration

According to the strategies presented the calculation of the harmonics of a signal are necessities in the three control approaches. For it, the fundamental harmonic component is obtained by means of a block with the scheme shown in Fig. 3. The instantaneous signal i is multiplied by $\sin \omega t$ and $\cos \omega t$ where ω is the fundamental frequency in rad/s. Two low pass filter (LPF) let obtain the mean values. The result obtained is multiplied by $\sin \omega t$ and $\cos \omega t$ again and by 2. The output of this set of operation is the fundamental component.

To calculate the harmonic components will be necessary to subtract this fundamental component to the input

instantaneous signal.

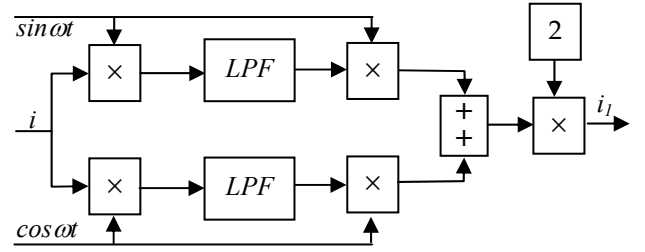


Fig. 3. Calculation fundamental component

In the first strategy, the input signal is the source current and the second strategy is the load voltage.

To obtained the control signal to the third strategy the expression (5) can be written in the form

$$v_{CHn} = k i_S - k_v v_L - k i_{SF} + k_v v_{LF} \quad (7)$$

Where:

- i_S : Source instantaneous current.
- v_L : Load instantaneous voltage.
- i_{SF} : Fundamental harmonic of i_S .
- v_{LF} : Fundamental harmonic of v_L .
- k : Constant to the current harmonics.
- k_v : Error in generate signal of v_{LH} .

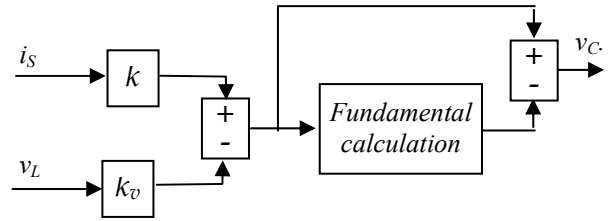


Fig. 4. Reference signal calculation in the 3th strategy

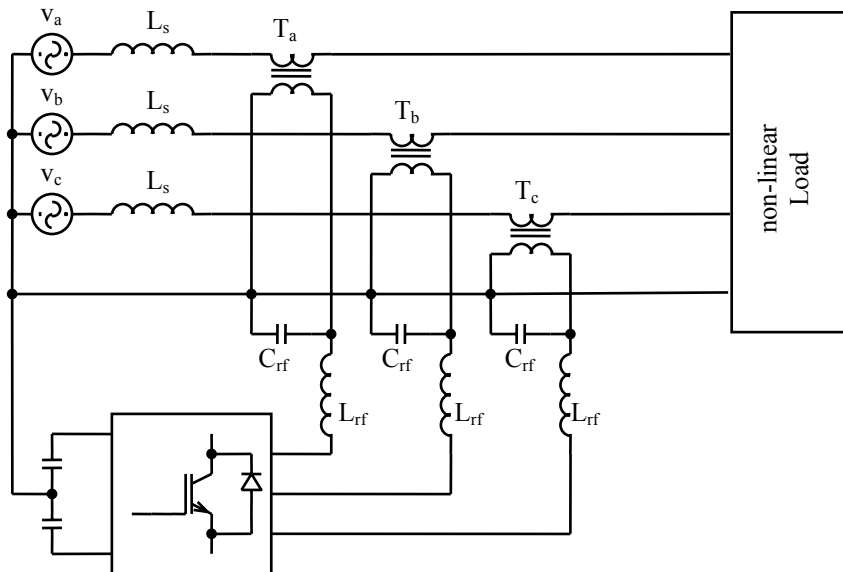


Fig. 5. Series active power filter topology

In this way the reference signal is obtained by the block diagram shown in Fig. 4. Where the block “fundamental calculation” is the same that the Fig. 3. It let determine the reference signal with less loss pass filter than using v_L and i_S as input signal in the Fig. 3.

To verify what was previously discussed a series active filter has been simulated. The scheme of the power circuit is shown in Fig. 5. It is a three-phase, four-wires system feed by a sinusoidal balanced three-phase source of 230 V rms with source inductance of 1 mH.

The inverter consists of an IGBT bridge. In the dc side two dc source of 100 V are connected. In the ac side a LC filter has been included to eliminate the high frequency components. The value of the high frequency inductor is 5 mH and the high frequency filter capacitor 10 μ F. This set is connected to the power system by means of three single phase transformers of turn ratio 1:1.

The non linear load consists of a non controller three phase rectifier with a capacitor of 10000 μ F connected in parallel with a resistance of 50 Ω in the dc side.

5. Simulation results

The system shown in Fig. 5 has been simulated in the platform Matlab-Simulink. Each one of the power devices have been modeled using the library of the toolbox of SimPowerSystem.

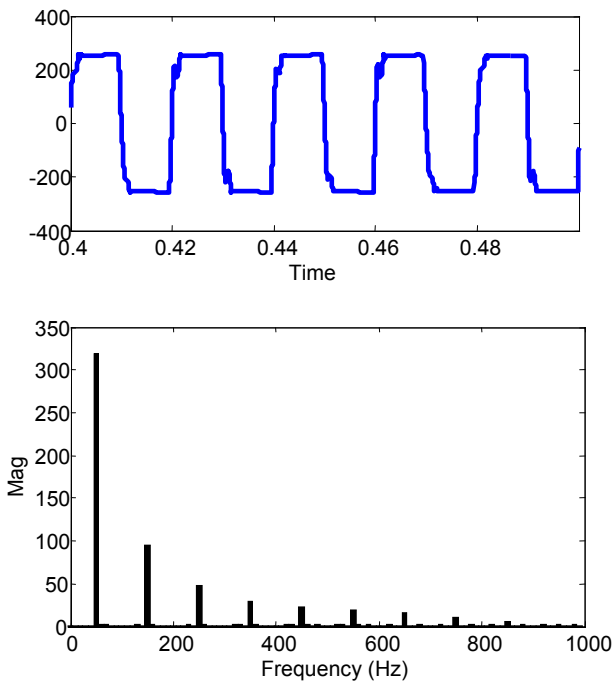


Fig. 6. Load voltage. Control $V_C = k I_{sh}$

The system has been simulated in the same situation to the three control strategies. It let compare the performance of the series active filter with the proposed controls.

The load chosen belong to voltage type harmonics-producing. The Fig. 6 shows the load voltage when the series active filter is not connected. The THD of this waveform is 36.76 %.

When the series active is connected and the first strategy is applied to obtain the reference signal, voltage on the source side can be improved. Fig. 7, shows the waveform and harmonic spectrum of the voltage on the source side when the constant spectrum applied has been $k=2$. The THD of the common coupling point voltage falls from 36.76% to 8.72%. This result can be improved with values of k higher, so for $k=20$ the THD obtained is 4.08%.

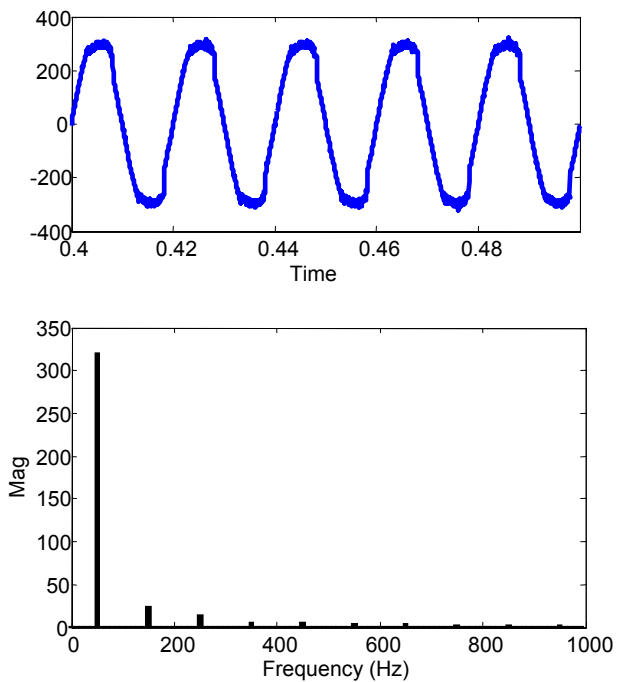


Fig. 7. Source voltage. Control $V_C = k I_{sh}$

In the next simulation presented, the second control strategy is applied. To calculate the reference voltage the value of constant k_v is 1. It means that there is not error in the measurement of the load voltage, however, the waveform generated by the inverter have an error, it is due to the hysteresis band of the PWM control. The waveform of the voltage on source side is shown in Fig. 8. The THD is 4.52%. When is considered a value of k lower than 1 the THD is higher. Therefore, the compensation features depend on the error of the measurement of the load voltage.

The third strategy combines the two previous control approaches. The Fig. 9 shows the waveform of the common coupling point voltage. The constant k is equal to 2 and the constant k_v equal to 1. The THD of the source voltage is 2.86%. Therefore, the measurement error has less influence in the compensation characteristic of the series active filter with this control.

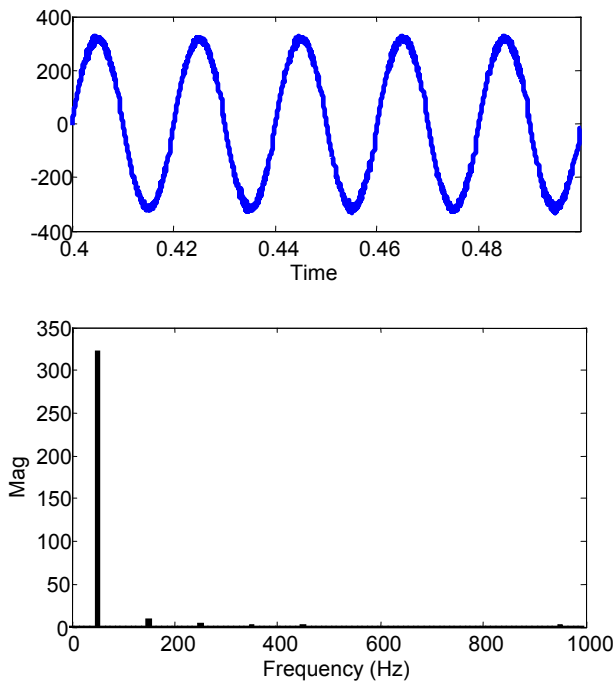


Fig. 8. Source voltage. Control $V_c = -k_v V_{Lh}$

On the other hand, the k value is lower than the necessary to improve the THD to 2.86 using the first strategy.

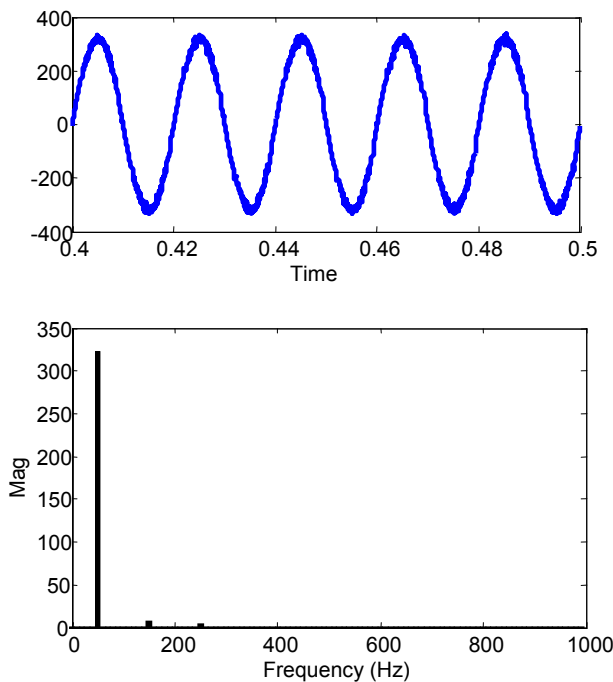


Fig. 9. Source voltage. Control $V_c = -k_v V_{Lh}$

4. Conclusion

Three different strategies have been analyzed and the simulation results using Matlab-Simulink have been presented.

When the control signal is proportional to the source current, the THD of the voltage on the side voltage is reduced, for high values of the constant k the THD falls but it can produce instabilities in the system.

The control strategy equal to load voltage harmonics achieves to reduce the voltage harmonics on the source side but is strongly influenced by the measurement error and the hysteresis band of the PWM control.

The hybrid control approach presents the best results. With this strategy, the measurement error has less influence in the compensation feature and the control can have slower cost than the simple strategies.

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