A New Topology and Control Strategy for Harmonic Elimination and Power Factor Correction Using a Series Active Power Filter

Majid Pakdel, Khalil Rahimi Khoshoei
Isfahan University of Technology
majidpakdel@yahoo.com, rahimi_kh@yahoo.com

***Abstract*-In this paper, a new topology and control strategy for harmonic suppression and power factor correction in single-phase systems using a series active power filter, are proposed. It is assumed that the active power filter is connected in series to a non-linear load and also draws harmonic current. Simulation results show that the designed active power filter is very effective in harmonic elimination and power factor correction of rectifiers with inductive or capacitive loads. The proposed topology and control strategy are more effective and flexible and also have lower cost and higher efficiency. The proposed topology and control strategy are discussed in details. Finally, the feasibility of such a scheme is demonstrated through simulation studies.**

***Index Terms*—Series active power filter, Harmonic elimination, Power factor correction.**

I. INTRODUCTION

Harmonic interference problems in power system become increasingly serious due to the wide application of power electronic equipments and non-linear loads in recent years. Harmonic contamination has become a major concern, because it affects the power utility in many aspects. Many methods have been proposed to solve it. Conventionally, shunt passive inductance-capacitance (LC) filters have been widely used to attenuate the power harmonic currents. However, shunt passive filters have many disadvantages, e. g., they may cause resonance phenomenon and the source impedance strongly affects the filtering characteristics [1].

To overcome these disadvantages, an active power filter has been proposed and developed in recent years. Harmonic pollution in electricity distribution systems is becoming so serious nowadays that the quality of the public supply is barely acceptable. In spite of poor quality of power supply, industry is increasingly connecting non-linear loads to the system. In some weak network areas, the voltage and current distortions are so large that, it is essential to use filters to avoid damage or malfunctioning in sensitive electric equipments. Further, low frequency harmonics (2^{nd} ~13^{th} harmonics) should be suppressed. Because, they can excite resonance in the electric network and cause problems such as over voltage, protection failure, mechanical stress and additional heating. Standards such as IEEE519 have specified limits for harmonic percents. Therefore, the harmonic percents of the single phase systems should also obey the standards.

The conventional shunt active filter [2], [3], injects compensating harmonic currents into the power system to cancel the harmonic currents contained in the loads so as to shape the source current into sinusoid. However, there are still some problems in their practical applications [4]. When conventional shunt active filter is used, the initial cost is very high and it is very difficult to realize a large rated PWM inverter with rapid current response. Nowadays, a lot of control methods such as UCI [5], sliding mode control [6], fuzzy control [7], adaptive neural network [8], fundamental magnetic flux compensation [9] and etc. have been proposed for controlling the active power filters. But, all of these methods require the high speed DSPs and are very expensive. Also, the methods based on instantaneous power theory [10], [11], [12], have complex calculations. A combined system of shunt passive and series active power filters [4], [13], are not easy to timely detect and follow harmonic currents until now.

In this paper, a new topology and control strategy for harmonic suppression and power factor correction in single-phase systems using a series active power filter is introduced. Comparing with other topologies and control strategies of the active power filter, the proposed topology and control strategy are very effective and flexible and have lower cost and higher efficiency. Simulation results are given to verify the analysis and demonstrate the topology and control performance.

II. TOPOLOGY AND OPERATION PRINCIPLE OF THE SERIES ACTIVE POWER FILTER

It is assumed that a non-linear load consisting of a single-phase diode rectifier with inductive or capacitive loads is connected to a sinusoidal voltage source. The inductive or capacitive load is considered as a series R-L or a shunt R-C respectively, which is connected to the DC side of the diode rectifier. Generally, an active power filter generates a harmonic spectrum that is opposite in phase to the distorted harmonic current it measures. Harmonics are thus cancelled and the result is a non-distorted sinusoidal current. The proposed topology for the power converter of the active power filter has been shown in Fig. 1. The MOSFET switches are connected in

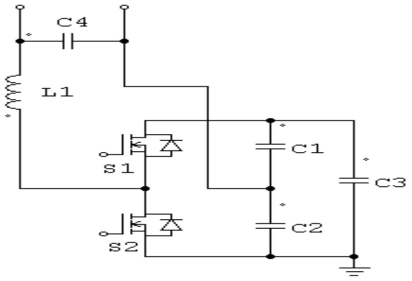

Fig. 1. The proposed topology for the series active power filter converter.

series and their on or off states are opposite to each other. The capacitor C4 at the output of the power converter operates as a high pass filter. Also, it blocks the fundamental current of the source from flowing in the power converter. Also, the inductor L1 blocks the fundamental source current. C1 and C2 have been used instead of the MOSFET switches in the conventional topology of the bridge converter. C3 is the DC capacitor that is used for supplying DC voltage to the power converter, and that is large smoothing DC link capacitor. The proposed topology for the series active power filter, voltage source and diode rectifier load are shown in Fig. 2.

The equivalent circuit of the system and the proposed topology of the series active power filter when the switch S1 is on and the switch S2 is off has been shown in Fig. 3. From Fig. 3, we have the following equation:

$$i_L = i_{Lf} + i_{Lh} \qquad (1)$$

Where i_{Lf} is the fundamental component of the load current and i_{Lh} is the harmonic component of the load current. In the series active power filter, a series voltage with the source voltage is used for harmonic compensation of the load current. Thus, if $i_{Lh} > 0$, then the harmonic current i_{Lh} is in the load direction. So, a series voltage should be applied in the opposite direction. It is caused a harmonic current in the opposite direction of the load harmonic current to cancel it. From Fig. 3 we know that:

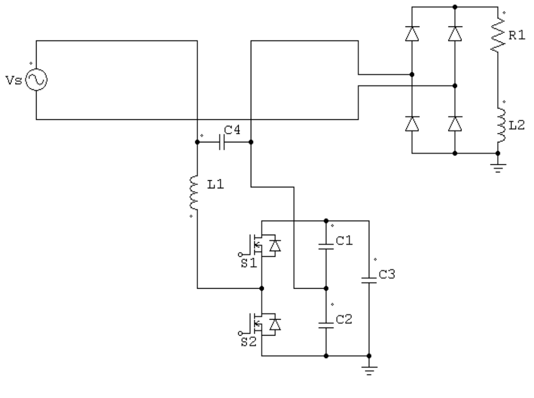

Fig. 2. The proposed active power filter topology, voltage source and rectifier load.

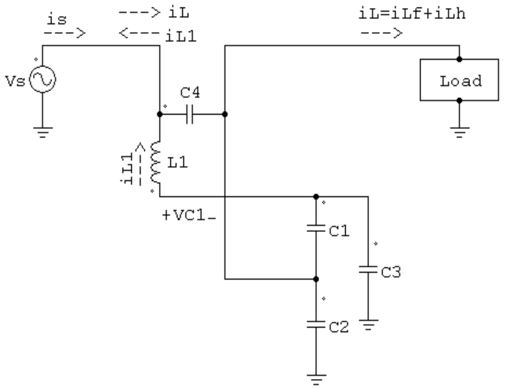

Fig. 3. Equivalent circuit of the system and active power filter in the case of S1=on, S2=off.

$$i_S = i_{L1} + i_L \qquad (2)$$

So, if we have the following condition:

$$i_{L1} = i_{Lh} \qquad (3)$$

From equations (1), (2) and (3), we would have the following equation:

$$i_S = i_{Lf} \qquad (4)$$

The equivalent circuit of the system and the proposed active power filter when the switch S1 is off and the switch S2 is on is shown in Fig. 4. In this case $i_{Lh} < 0$, thus, the harmonic current i_{Lh} is in the opposite direction of the load. Therefore, a series voltage should be applied in the load direction. It is caused a harmonic current that cancels the load harmonic current i_{Lh}. Thus, in this case, we have also the following equation:

$$i_S = i_{Lf} \qquad (5)$$

III. CONTROL STRATEGY

The control strategy has been used in the proposed topology of the active power filter is shown in Fig. 5. In this figure, a

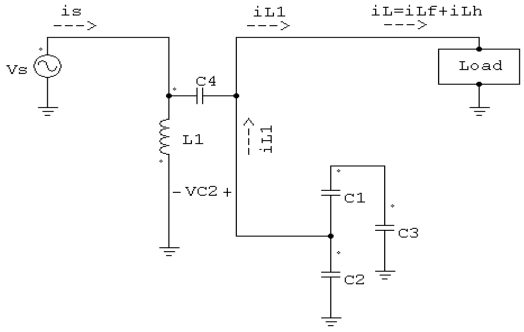

Fig. 4. Equivalent circuit of the system and active power filter in the case of S1=off, S2=on.

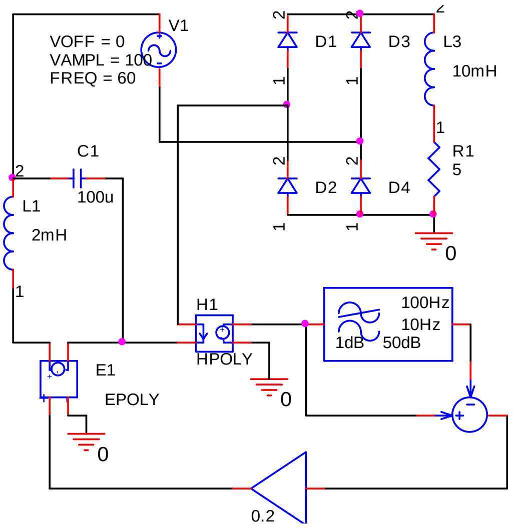

Fig. 5. Control strategy of the active power filter.

low pass filter and a subtraction has been used for generating harmonic components of the load current. The low pass filter extracts the low frequency components of the load current. The low pass filter has the attenuation factor of 1 dB in 10 Hz and 50 dB in 100 Hz. Then, the filtered load current is subtracted from the load current, to achieve the harmonic components of the load current. The series active power filter is shown with an ideal voltage to voltage converter. At the output of the ideal voltage to voltage converter, the inductor and capacitor are used as discussed before. The waveforms of simulation using the Orcad 9.2 software have been shown in Fig. 6 to Fig. 9. Switching control of MOSFETs is shown in Fig. 10. The frequency of the triangle signal is selected 1 kHz. Voltage control of DC capacitor has been shown in Fig. 11. We assumed that the DC capacitor voltage of the active power filter is constant, which requires the net average active power flowing into the capacitor during one cycle to be zero. However, it cannot be automatically guaranteed in the actual circuit. So, a voltage feedback control as shown in Fig. 11, is added to regulate the capacitor DC voltage of the active power filter. In this circuit, the actual DC capacitor voltage is detected and compared with the reference value, and the error is added to a signal in phase with the source voltage. The result is added to the load harmonic current. By adding the sinusoidal offset and the harmonic current, active power flowing into the capacitor will be changed, thus the DC capacitor voltage can be controlled.

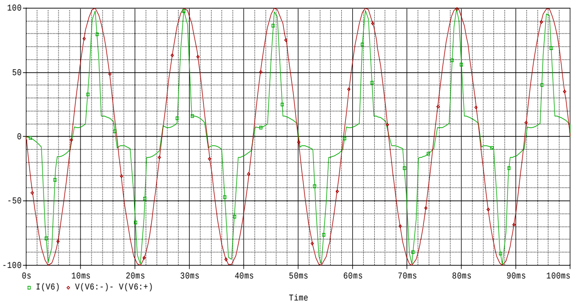

Fig. 6. Source voltage and uncompensated source current.

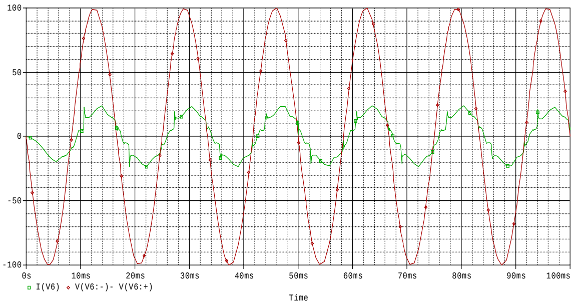

Fig. 7. Source voltage and compensated source current.

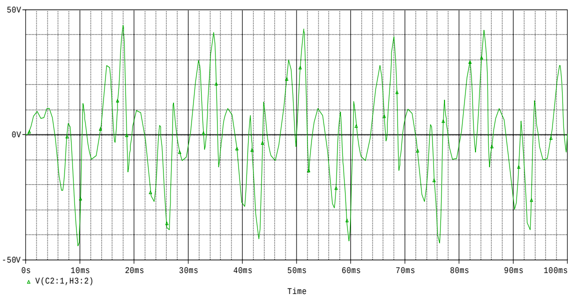

Fig. 8. The voltage across the capacitor C1.

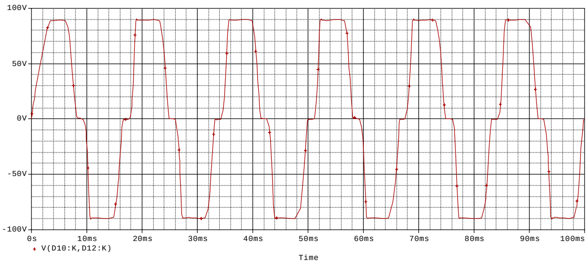

Fig. 9. Voltage across the load (rectifier)

IV. SIMULATION RESULTS

According to the analysis above, the proposed topology and control strategy of the series active power filter are simulated using the Orcad 9.2 software. The supply voltage amplitude is considered to be 100 V with the frequency of 60 Hz. The value of V_C^* is chosen 90 V. The values of capacitors used instead of MOSFETs are selected $560\,\mu F$. The value of the DC capacitor is chosen 4.7mF and the values of L and C at the output of the power converter are selected 2 mH and $100\,\mu F$ respectively. It is assumed that the following loads are connected to the DC side of diode rectifier:

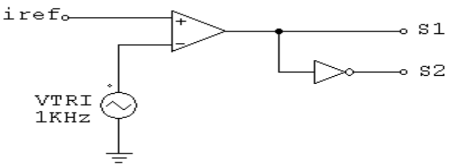

Fig. 10. Switching control of MOSFETs.

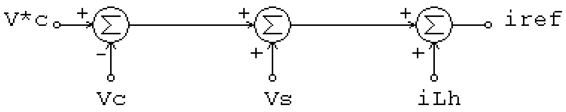

Fig. 11. Voltage control of DC capacitor.

(I) Series R-L with the values of $R = 2.2\,\Omega,\ L = 10\,mH$.
(II) Shunt R-C with the values of $R = 4.7\,\Omega,\ C = 2.2\,mF$.

Also, for filtering of the high frequencies of the series active power filter and improving the waveform of the source current in the case (II), the passive R-C high pass filter with the values of $R = 1\Omega,\ C = 270\ \mu F$ is connected across the voltage source.

The block diagram of the designed system using the Orcad 9.2 software has been shown in Fig. 12. The simulation results for the proposed topology and control strategy of the series active power filter are shown in the following figures (from Fig. 13 to Fig. 20).

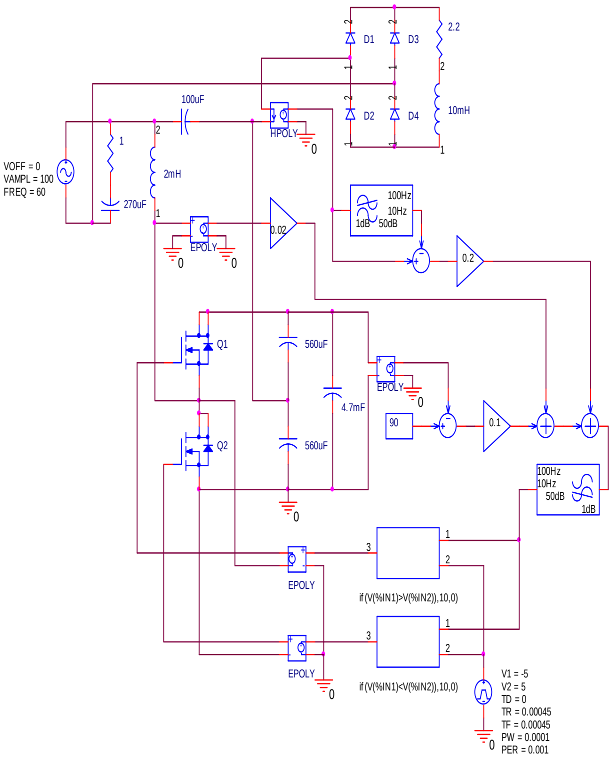

Fig. 12. Block diagram of the designed system, using the Orcad 9.2 software.

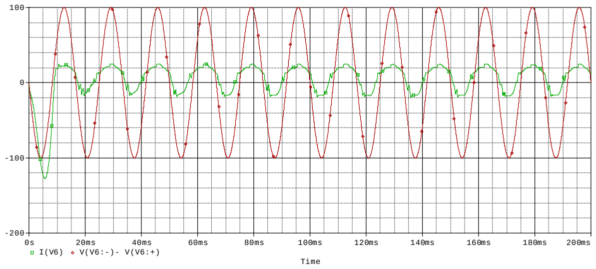

Fig. 13. Source voltage and current in the case (I).

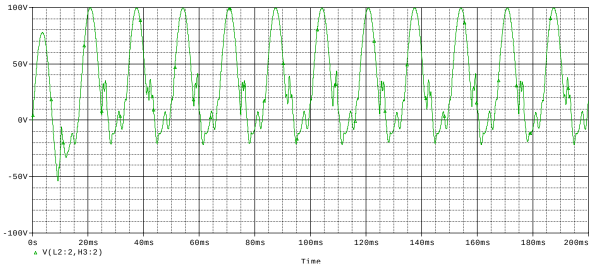

Fig. 14. The voltage across the capacitor C4 in the case (I).

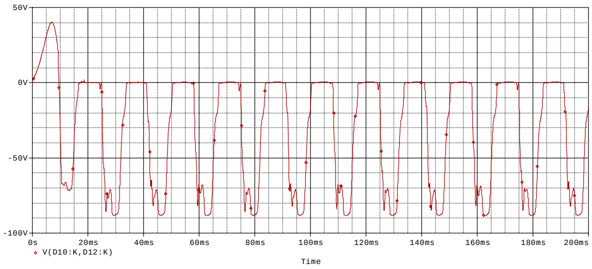

Fig. 15. The voltage across the load in the case (I).

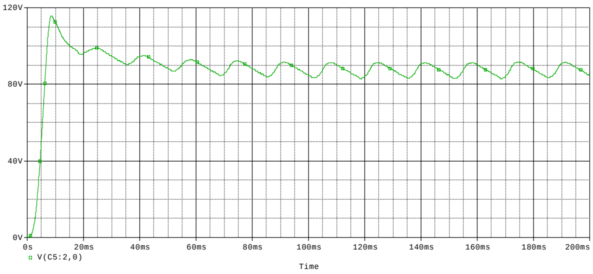

Fig. 16. The voltage across the DC capacitor in the case (I).

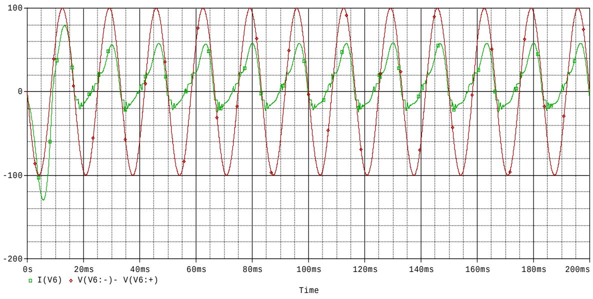

Fig. 17. Source voltage and current in the case (II).

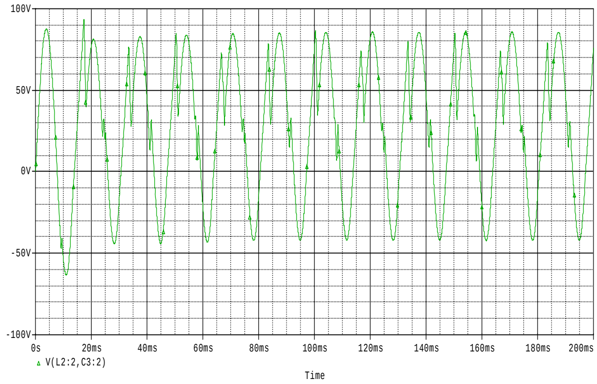

Fig. 18. The voltage across the capacitor C4 in the case (II).

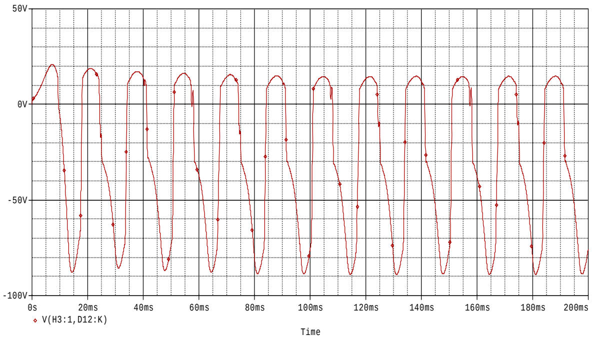

Fig. 19. The voltage across the load in the case (II).

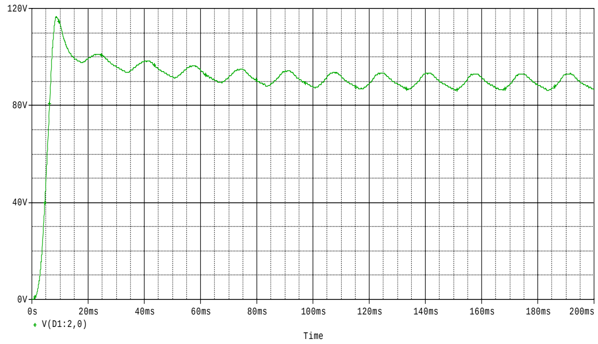

Fig. 20. The voltage across the DC capacitor in the case (II).

As shown in Fig. 13 to Fig. 20, the designed series active power filter is very effective in harmonic suppression and power factor correction purposes. The designed active power filter can successfully compensate the harmonic currents of the rectifier with capacitive or inductive loads. The designed active power filter can also compensate the harmonic currents of other non-linear loads. The proposed topology from economic aspect and performance is preferred to the other topologies. Also, the proposed control method is very simple and has lower cost. The PI controller is not used in the DC capacitor voltage control. This is another advantage of this control strategy.

V. CONCLUSION

In this paper, a new topology and control strategy for harmonic elimination and power factor correction using a series active power filter are proposed. The simulation results with the designed active power filter show that this topology and control strategy is very effective in harmonic current compensation of rectifier with capacitive or inductive loads. Also, it can compensate harmonic currents of other non-linear loads. This control method improves the power factor of supply side effectively. The designed series active power filter and its control strategy can be implemented with lower cost in practice and it has higher efficiency.

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