Power System Harmonic Mitigation using Hybrid Filters

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Abstract—**Due to the rapid development in power electronic devices, harmonic level in distribution networks has significantly increased during the last two decades. This calls for effective harmonic mitigation techniques to maintain the power quality of electricity grids. This paper introduces various designs for hybrid filters and proposes an optimal design based on the simulation results which show that in order to obtain balanced and pure sinusoidal waveforms, the shunt active filter is the best candidate. Simulation results also show that when series component in a hybrid filter is connected to the load side, it results in undesirable distorted signal.**

Keywords — Hybrid Filter, THD, Active Filter, Passive filter.

I. INTRODUCTION

Most litratures reveal that the performance of power system sensors and other equipment in presence of harmonics is not significantly affected when the total harmonic distortion (THD) is less than 20% [1]. Due to the rapid development in power electronic devices and the significant penetration of wind turbines and electrical vhicles to power systems, harmonic level in power grids has significantly increased during the last two decades [2]. Initially, the mitigation of harmonics was performed by using shunt passive filters that were cost effective solution [3]. However, the effectiveness of passive shunt filters become unreliable when there are variations of either harmonic orders injected to the grid or if there is a slight change to the fundamental frequency. Parameters of shunt passive filters are designed to eliminate particular harmonic orders which represents the main drawback of this types of filters [4]. Unlike shunt passive filters, an active filter generates current spectrum that is opposite in phase and equal in magnitude to the undesirable harmonic current to result in a non-distorted sinusoidal current. Active Filters are able to alleviate the disadvantages of conventional passive filters that include its dependency on source's impedance and its inadequacy to filter out non-characteristic harmonics [5].

There are two main types of active filters based on their connection to the network namely; series type which is used to prevent the transfer of harmonic currents in transmission line and shunt type which is used to reduce the harmonic content at the point of common coupling [6], [7]. Although the shunt active filter has definite technical advantages over passive filter, its cost is still relatively high.

In this paper various designs for active filters are assessed and an optimal design is proposed based on the simulation results.

II. ACTIVE FILTER

This section briefly elaborates the configuration of the two types of active filters.

A. Shunt Active Filter

The voltage source inverter (VSI) based shunt active filter shown in Fig. 1 is the most common type due to its simplicity [4], [8-10].

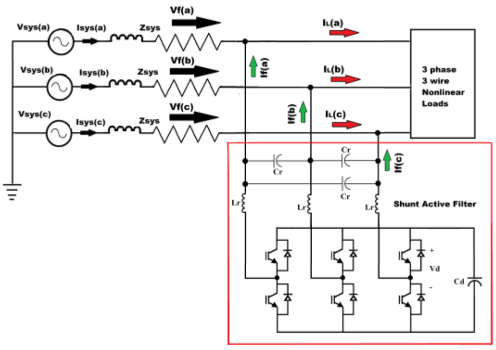

Fig. 1. Configuration of a VSI based Shunt Active Filter [4]

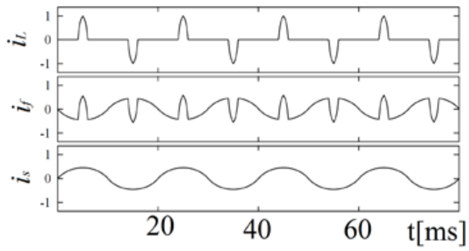

Fig. 2. Shunt Active Filter Harmonic Filtering Operation Principle [8]

Fig. 2 shows the basic operation of a shunt active filter that acts as a current source injecting a compensation current that is equal in magnitude and in opposite direction to the distorted current, thus eliminating the original distorted current. This is achieved by "shaping" the compensation current waveform i_f, using the VSI switches. The shape of compensation current is obtained by measuring the load current i_L and subtracting it from a sinusoidal reference to obtain a sinusoidal source current i_s.

B. Series Active Filter

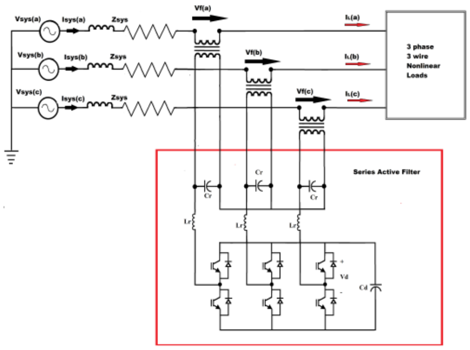

Fig. 3. Configuration of a VSI based Series Active Filter [4]

Fig. 3 shows the principle configuration of series active filter which is connected in series with the distribution line through a matching transformer. As shown in Fig. 3, the principle configuration of series active filter is similar to shunt active filter, except that the interfacing inductor of shunt active filter is replaced with an interfacing transformer. The principle operation of series active filter which can be considered as a harmonic isolator as shown in Fig. 4 is based on the isolation of harmonics transfer between the nonlinear load and the source. This is obtained by the injection of harmonic voltages v_f across the interfacing transformer which is subtracted from the source voltage to maintain a pure sinusoidal voltage waveform across the nonlinear load.

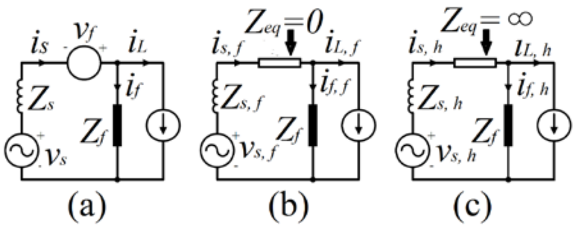

Fig. 4. Principle Operation of Series Active Filter (a) Single Phase Equivalent of Series Active Filter, (b) Fundamental Equivalent of Series Active Filter, and (c) Harmonic Equivalent Circuit [8]

III. SIMULATION RESULTS

In this section various design configurations of active filters are assessed in order to propose an optimal effective design to eliminate harmonic contents in a heavily distorted distribution network. All designs are implemented for a 50 Hz, 240 V distribution network with total harmonic distortion of 41.6% and with the existence of the 5^{th}, 7^{th}, 11^{th}, 13^{th}, and 17^{th} harmonic orders as summarized in Table I.

TABLE I: HARMONIC ORDERS AND THEIR FREQUENCIES

Harmonic order	Frequency (Hz)	Amplitude (pu)
Fundamental	50	1
5^{th}	250	0.30
7^{th}	350	0.187
11^{th}	550	0.146
13^{th}	650	0.125
17^{th}	850	0.104

A. Design (1): Hybrid filter with Two Series Filters and One Shunt Passive filter between the two active filters

Fig. 5 shows a single line diagram of the configuration of this design where the shunt passive filter and the two series active filters (AF) connect the non-linear load to the source through a T-network. Fig.6. Shows that the output 3-phase voltages are unbalanced since the voltage across phase B (V_{outC}) is a bit higher than the other two phases which is evidenced by the harmonic spectra of the waveforms shown in Fig. 7. Although the resultant waveforms are purely sinusoidal, this design of hybrid filter is unacceptable.

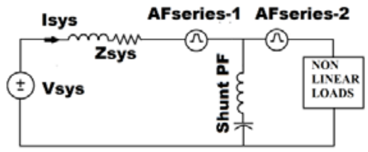

Fig. 5. Hybrid Filter with Two Series Filters and One Shunt Passive filter between the two active filters [4]

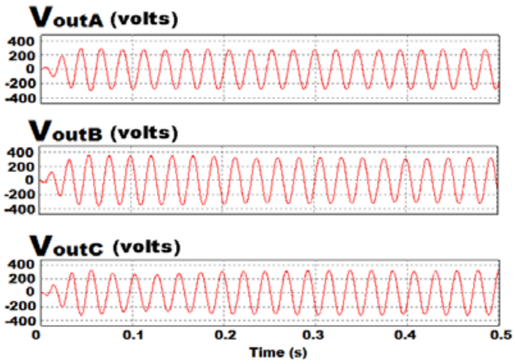

Fig. 6. The filtered output voltages of Design 1

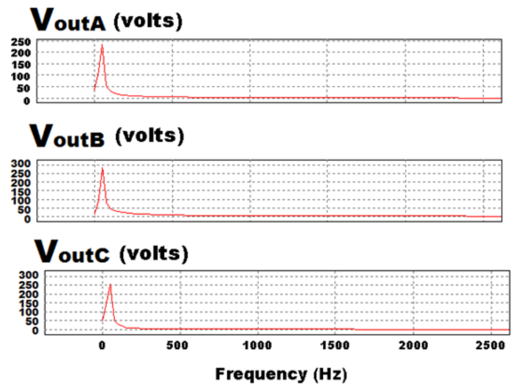

Fig. 7. Harmonic Spectra of the output voltages of Design (1)

B. Design (2): Hybrid filter with One Shunt Active Filter in series with One Shunt Passive filter and One Series Filter

In this design, shunt passive and active filters are connected in series to form a Γ-network with the active series filter used in this configuration as shown in Fig. 8. Fig. 9 shows that this design is acceptable as the output of this configuration is balanced and has no distortions as can be seen in the harmonic spectra of the output 3-phase voltages shown in Fig. 9.

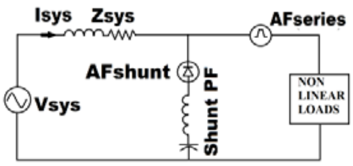

Fig. 8. Hybrid Filter with One Shunt Active Filter in series with One Shunt Passive filter and One Series Filter [4]

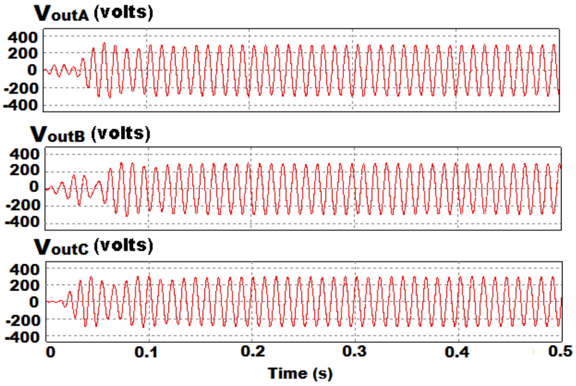

Figure 8. The filtered output voltages of Design 2

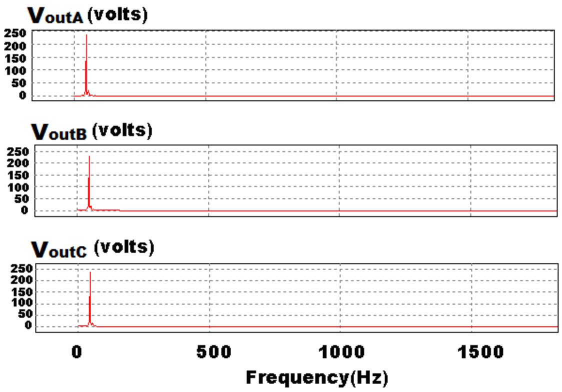

Fig. 9. Harmonic Spectra of the output voltages of Design (2)

C. *Design (3):Hybrid filter with One Series Filters, One Shunt Active Filter in series with One Shunt Passive filter*

Fig. 10 shows the design of this configuration is similar to design (2) except that the used active series filter is moved to the source side instead of the load side.

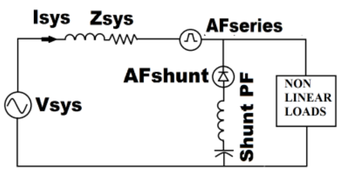

Fig. 10. Hybrid Filter with One Series Filters, One Shunt Active Filter in series with One Shunt Passive filter [4]

Similar to previous design, this design results in balanced voltages and there are no distortions in the output signals as can be seen in the output voltage waveforms shown in Fig. 11 and its harmonic spectra shown in Fig. 12. This design is also acceptable.

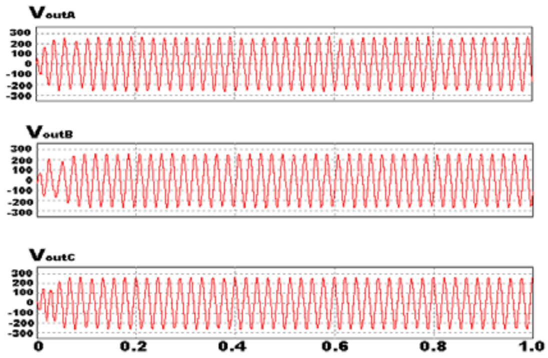

Fig. 11. The filtered output voltages of Design (3)

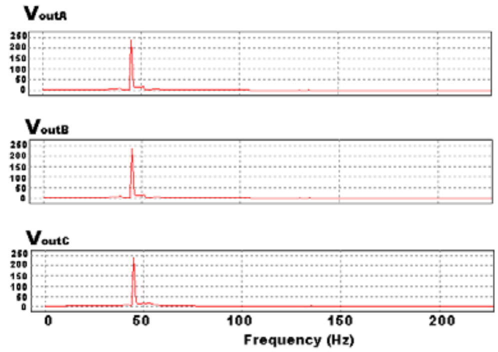

Fig. 12. Harmonic Spectra of the output voltages of Design (3)

D. *Design (4): Hybrid filter with two Shunt Active Filters and One Shunt Passive Filter*

In this design, no series active filter is used and the non-linear load is connected to the source via two shunt active filters and one passive filter as shown in Fig. 13.

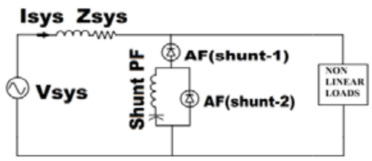

Fig. 13. Hybrid Filter with two Shunt Active Filters and One Shunt Passive Filter [4]

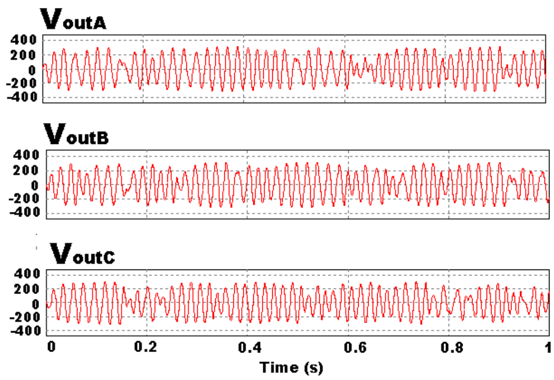

Fig. 14. The filtered Output voltages of Design (4)

This design is unacceptable since it provides unbalanced and distorted output voltages as shown in the voltage waveforms and its harmonic spectra (Figs. 14 and 15 respectively).

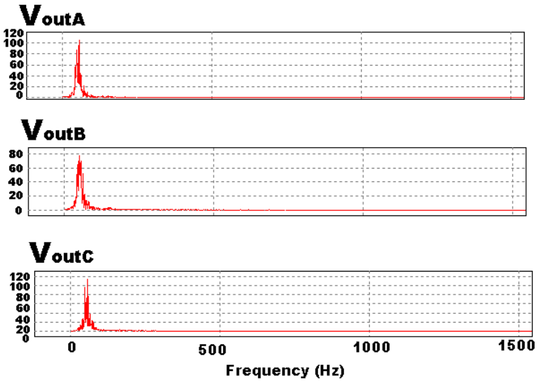

Fig. 15. Harmonic Spectra of the output voltages of Design (4)

E. Design (5):Hybrid filter with Series Filter, One Shunt Active Filter and One Shunt Passive filter

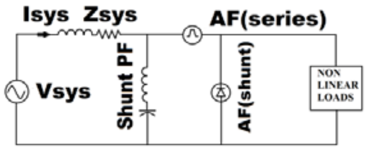

Fig. 16. Hybrid Filter with One Series Filters, One Shunt Active Filter and One Shunt Passive filter [4]

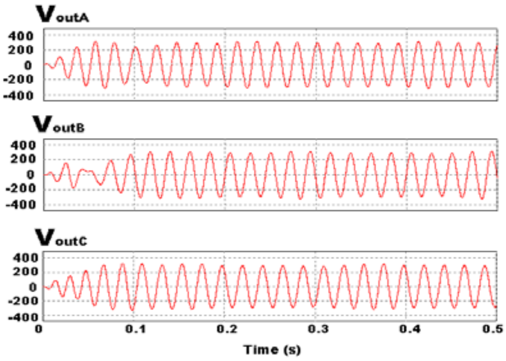

Fig. 17 The filtered Output voltages of Design (5)

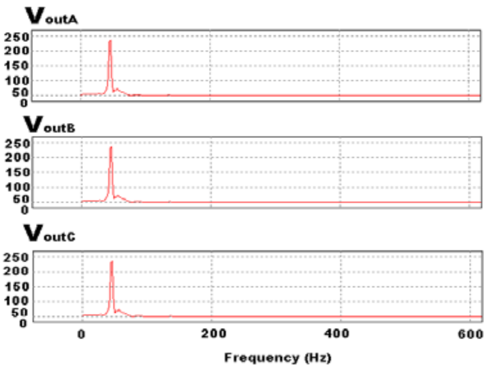

Fig. 18. Harmonic Spectra of the output voltages of Design (5)

Configuration of this design is shown in Fig. 16 and its output 3-phase voltage waveforms and its harmonic spectra are shown in Figs. 17 and 18 respectively. Results reveal that this design is acceptable too as it results in balanced and non-distorted voltages.

The above results show that hybrid filter configurations of designs (2), (3) and (5) can be used to effectively eliminate the undesired harmonics in a heavily distorted network. These designs encompass active series and active shunt filters in addition to passive filter. On the other hand, designs that include only series or shunt active filters such as design (1) and (4) are not adequately mitigating all harmonic contents in the voltage waveform.

IV. CONCLUSION

Five different configurations of hybrid filter design are assessed in this paper. Simulation results show that hybrid filters containing active and passive filters result in balanced and undistorted voltage waveforms. On the other hand, simulation results show that the use of active filters only is not effective in mitigating all harmonic contents. Among the five configurations studied in this paper, design (2), (3) and (5) can be considered as optimum designs as they have the capability of eliminating all undesired harmonics with the less numbers of filters used in the design.

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