Novel Power Quality Enhancer based on a Multilevel Inverter 1

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Abstract - **The hybrid approach of active and passive filter combination is used to eliminate the harmonics in non-linear load is presented in this paper. The objective of the proposed work is to mainly concentrate on reduction of load current harmonics and power factor improvement. The active filter is used to eliminate low order high amplitude harmonics, which is not an economic solution. Even though the passive filters are accepted as cost-effective solution, there is a chance for occurrence of resonance in the system. In this condition, the combination of filters may help to improve filtering characteristics. This strategy improves the passive filter compensation characteristics without depending on the system impedance and avoiding the resonance problem. The combined hybrid filter is designed and simulated in MATLAB/Simulink environment. The performance is analyzed, compared with various conditions, and results are presented.**

Keywords-component; Power Quality, Shunt Hybrid Filter (SHF), Space Vector Pulse Width Modulation (SVPWM), Total Harmonic Distortion (THD), Power Factor Improvement, VSC Inverters.

I. INTRODUCTION

In the past years, there has been a great rise in the usage of non-linear loads in the power supply networks. The deformed voltages are caused due to current harmonics utilized by the non-linear loads flowing through the line impedance, and the major harmonics are extended to the remaining network. There are some probabilities to reinstate the power quality in power systems, [1,2]. Hence, the passive filters resonant with the main harmonic frequencies are a regular solution when the current harmonics are identified. The filter is of lowest cost and it forms a main advantage. But, there are some disadvantages too. Essentially that the filter does not remove further harmonics and resonance complications with the system impedances can occur. Latest development of signal processing and power converters permit us to use the active power filters (APFs) to enhance the electrical power quality [3,4].But the price of those APFs are its main disadvantage.

It is feasible to combine passive and active filters to obtain the advantages of both filters. Several schemes have been realized [5,11]. The objective of this work is to remove the load harmonics by modeling a shunt hybrid passive-active filter. The passive filter having some LC branches contributing null impedance to the main current harmonics are connected in parallel. The APF and the passive filter are connected in series with each other. Figure 1 shows the diagram of the compensated system.

Three-phase diagram of proposed shunt hybrid filter is shown in Fig. 1. Two passive LC branches are connected in series with an active filter. If the active filter is not connected, the compensation current, i_c, mitigates the main harmonics of load current i_l, and it is possible that a series resonance between the LC branches will appear. So the source current, is will

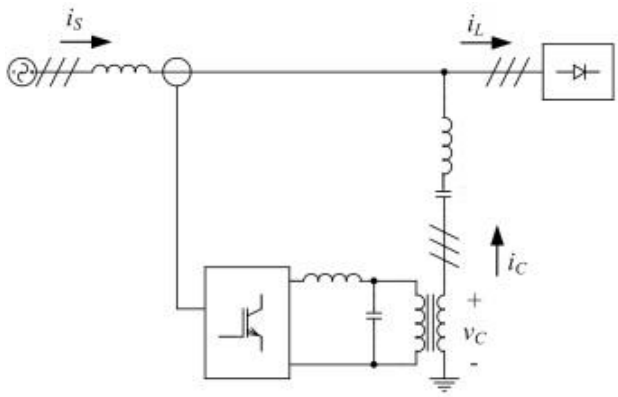


Figure 1. Three-phase system compensated with a hybrid filter

include certain harmonics and the distortion is not completely reduced. If the active filter is included, an appropriate control allows modifying the impedance of shunt compensator at resonance frequencies, and the problem can be avoided.

Using MATLAB / Simulink software, the functioning of the hybrid filter is verified. A three-phase diode rectifier has been compensated by a hybrid filter consisting of two-branch shunt passive filter in series with an active power filter.

II. HYBRID FILTER DESIGN

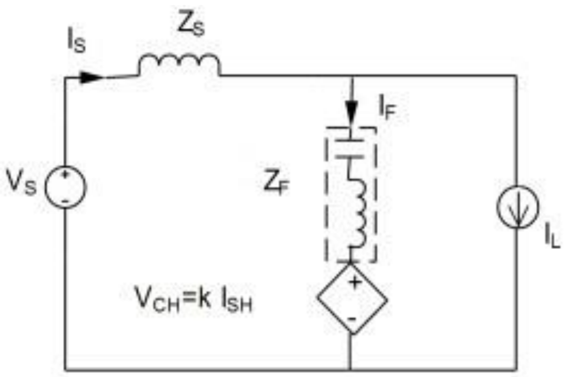
The load to be balanced, decides the filter hybrid design. It must comprise some passive LC branches, having one for each important load current harmonic to be isolated from the source current. In the case of many common loads, it is usually enough to occupy one, two or three branches for the main harmonics. By three-phase techniques it is possible to reduce or eradicate the 3rd harmonic order and its multiples by suitable connections of the transformers supplying the power to the load.

Hence it is usual to include LC branches tuned for the 5th and 7th harmonic order. The values of the L_n and C_n parameters of a branch tuned for an "n" order harmonic must satisfy the equation (1).

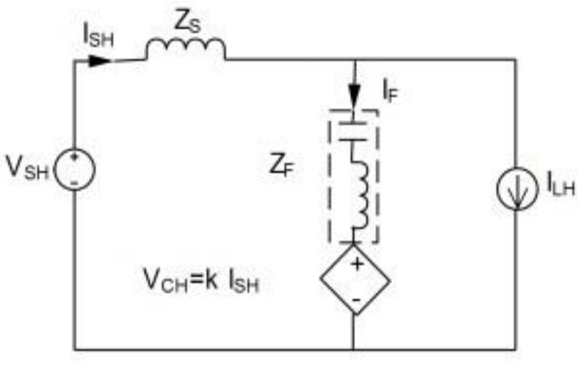
$$\omega_n = 2\pi \text{ f n} = \frac{1}{\sqrt{L_n C_n}} \quad (1)$$

Where f refers to the fundamental frequency and it is taken as 50Hz in this work.

The active filter connected in series with the passive branches can be seen as a controlled voltage source. Different schemes are possible to control this compensation voltage. In single-phase or balanced three-phase systems, a voltage V_C proportional to the source harmonic current I_{SH} allows to modify the impedance of the shunt compensator, and the passive filter performance is improved. Figure 2a shows the equivalent single-phase circuit for the compensated system.



(a)



(b)

Figure 2. a. Equivalent circuit of the compensated system and b. Equivalent circuit for harmonic of order H.

The current source can be modified using the non-linear loads.

Figure 2b shows the equivalent circuit for a determined harmonic of order H. From the circuit 2b, it is possible to obtain the source harmonic current, equation 2.

$$I_{SH} = \frac{Z_F}{(Z_s + Z_F + K)} L_{LH} + \frac{1}{(Z_S + Z_F + K)} V_{SH} \quad (2)$$

If K=∞, then preferably the source harmonic currents will be null. The series resonance between the source and the filter can be reduced if the strategy is $K >> (Z_S+Z_F)$. It avoids that the passive filter receives the harmonic current of the rest of the system. In the practical case simulated in this work a value of K=2 is used.

The output voltage of the active power converter does not contain any desired high-frequency harmonics, which is caused by the operation of switching devices. With the norms of a transformer, series connection with the LC branches is carried out. This enables to have low voltages at the side of the inverter. The three phase circuit under study is shown in figure.3.

III. SIMULATION RESULTS

A. System Discription

In this work, a three-phase diode rectifier has been compensated to check the hybrid filter performance. Figure 4 shows a schematic diagram of the three phase diode rectifier. The harmonics measurements are carried out at the load terminal at the point of common coupling. It presents mainly 5th and 7th order harmonics are having major effects as shown in the figure 5. The harmonics measurements are done using MATLAB/ SimPowerSystem toolbox.

Table I shows the compensated system parameters values. It includes the source impedance parameters L and C values for both passive branches used, and the power rate needed for the active power filter.

As it can be observed in Table I, the APF power used is very low, and consequently the costs of the designed filter are also reduced. The system has been simulated without and with the active power filter to compare the performance of passive and hybrid filter.

In this case, only the LC passive branches are connected in parallel with the load. There is series resonance between the source impedance and each LC branch. The source current obtained is not exactly sinusoidal it includes 5th and 7th order harmonics.

Figure 6 presents the load, the filter and the source current waveforms of phase – 1. With the passive filter connected, the total harmonic distortion is reduced, but the resonance does not allow a greater reduction. Table II shows the THD values of source current before and after the compensation.

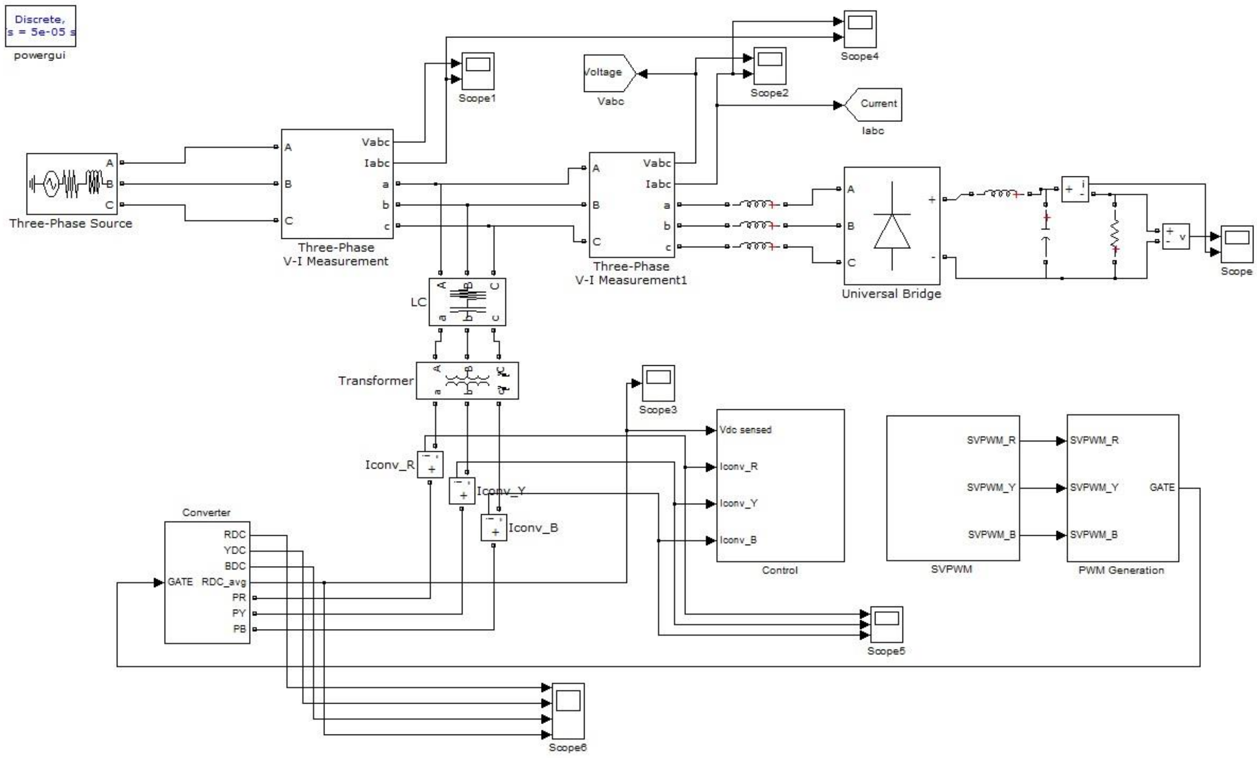


Figure 3. Block scheme of a three phase system compensated by the proposed hybrid filter

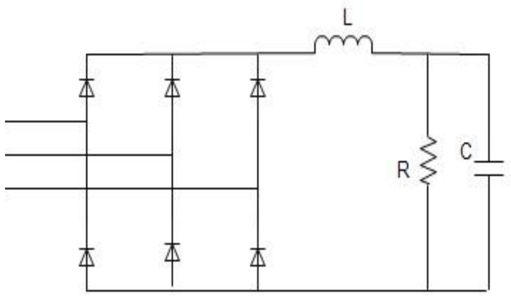


Figure 4. Schematic diagram of a three phase diode rectifier

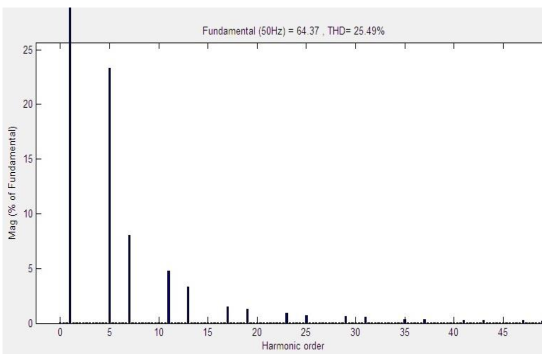
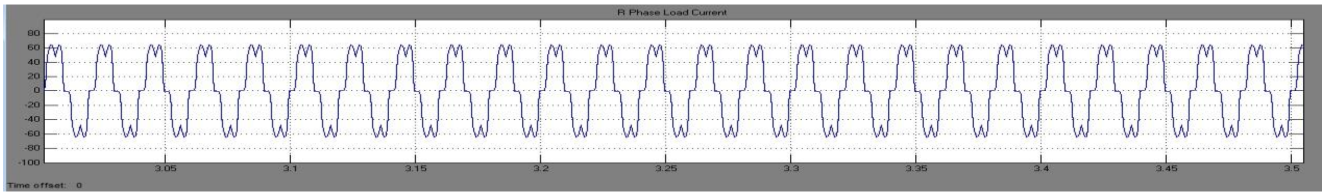


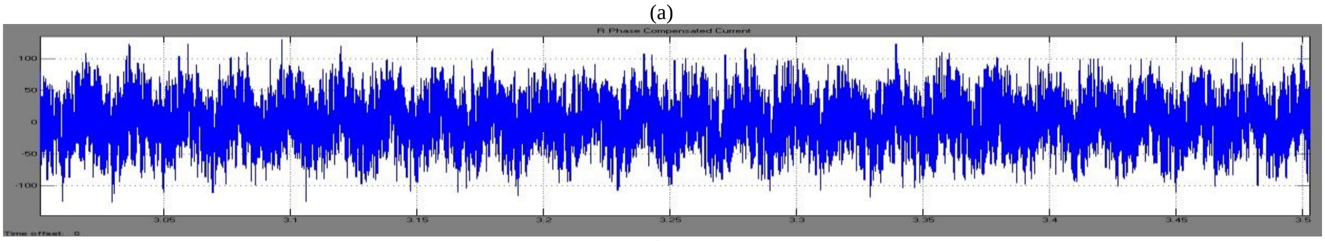
Figure 5. Peak Magnitude of Harmonic Spectrum of phase-I load current

TABLE I SYSTEM PARAMETERS IN A PRACTICAL CASE: A THREE-PHASE RECTIFIER WITH A PARALLEL PASSIVE AND ACTIVE FILTER

Power circuit source	Phase-to-phase voltage = 400 V_{RMS} Frequency = 50Hz Source resistance = 0.002Ω Source inductance = 2mH
Load	Apparent Power = 45kVA Load DC side resistance R = 6Ω Load DC side inductance = 0.4mH Load DC side capacitor C = 1 µF
Passive Filter	5^{th} order branch inductance L5 = 4.05mH 5^{th} order branch capacitor C5 = 100µF 7^{th} order branch inductance L7 =5.669mH 7^{th} order branch capacitor C7 = 75 µF
Active Filter	Apparent Power = 0.24kVA



(a)



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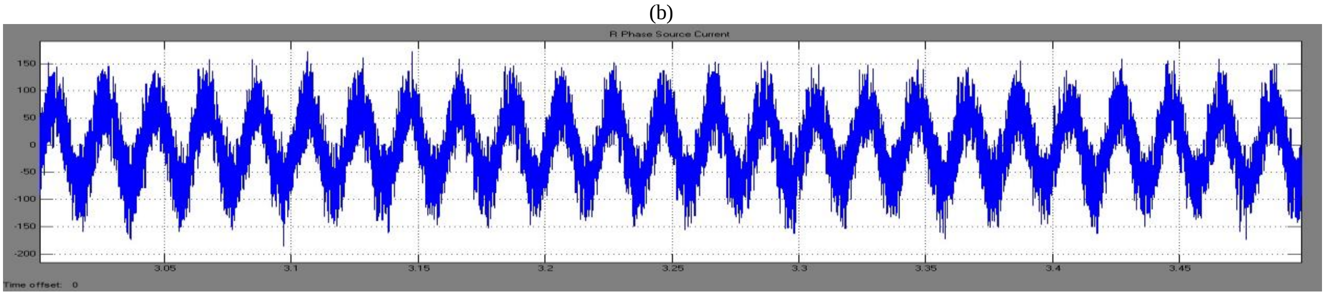
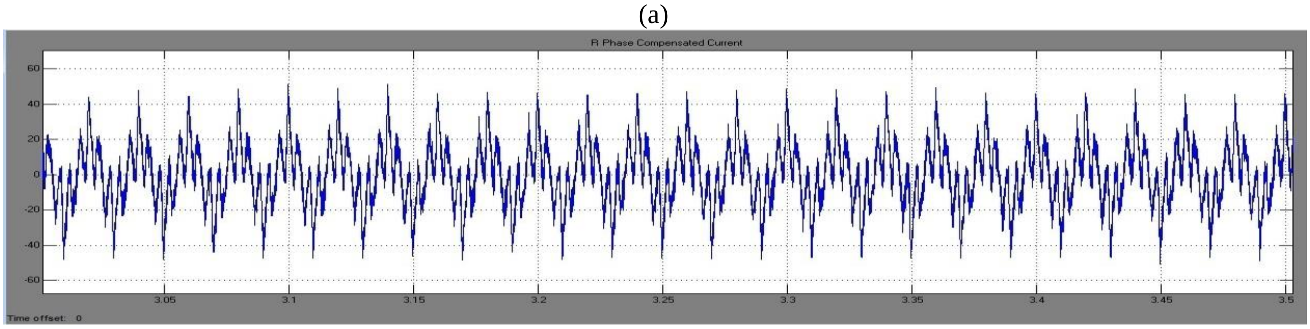


(c)

Figure 6 Phase – I currents at compensated system a) Load Current, b) Compensation Current, c)Source Current

(a)



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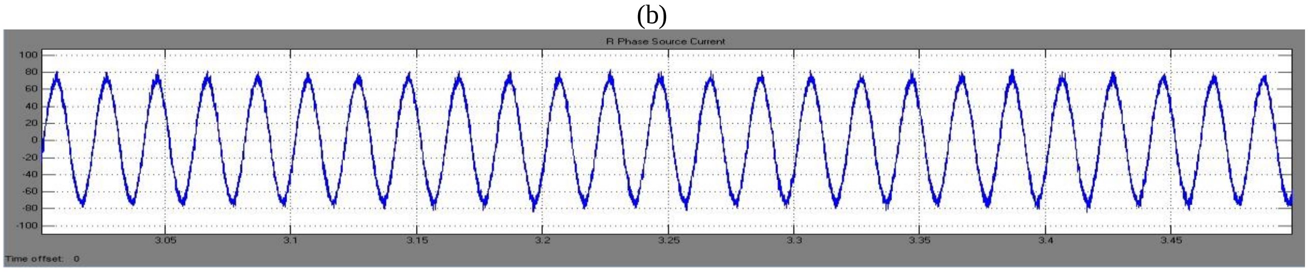

(c)

Figure 7 Phase – I currents at compensated system a) Load Current, b) Compensation Current, c)Source Current

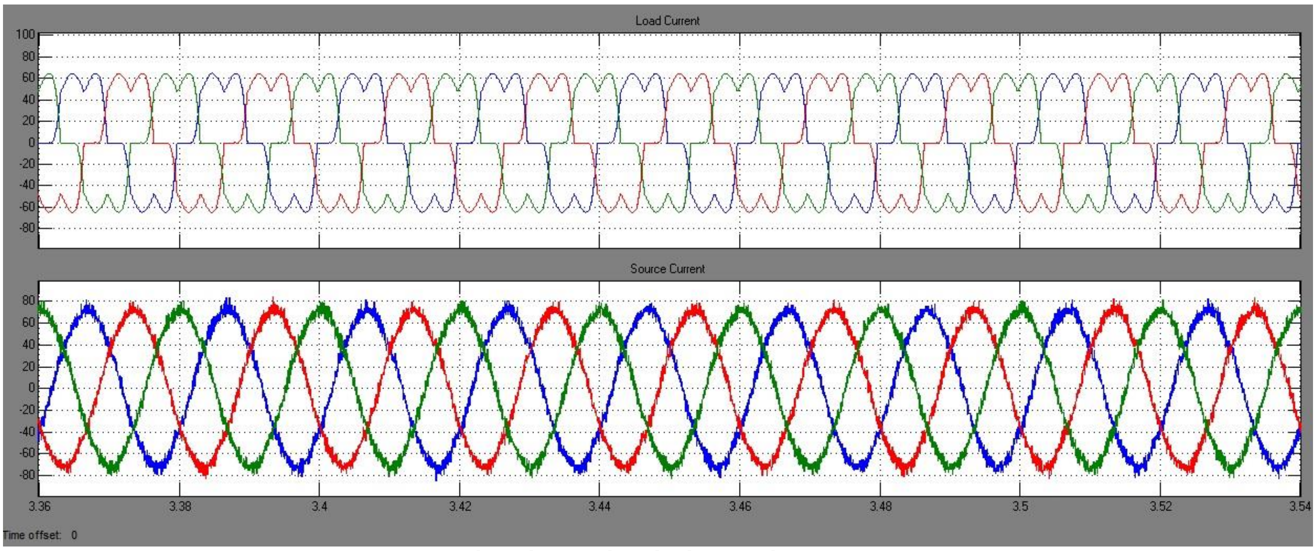

Figure 8 Three phase results a) load currents b) source currents

Table – II Source current THD values, before and after the passive filter compensation

Source Current	THD
Before the compensation	25.49%
After the compensation	9.13%

Table – III Source current THD values, before and after the hybrid filter compensation

Source Current	THD
Before the compensation	25.49%
After the compensation	4.3%

B. Hybrid Filter Compensation

When the active power filter is connected in series with the passive branches, the resonance is damped. The hybrid filter allows compensating the load harmonics, and the source current becomes sinusoidal. Figure 7 presents the load, the filter and source current waveforms of one phase in the compensated system. Figure 8 shows all-phase load and source currents.

The source current distortion values before and after compensation are shown in table III. The Total Harmonic Distortion is reduced from 26% to 4% using an ideal inverter in the APF to follow the reference compensation current.

IV. Conclusion

A shunt hybrid power filter has been proposed to compensate the load current harmonics. While a shunt passive filter eliminates the main load harmonics, an active power filter eliminates the problem. The global filter performance is also improved. The solution is effective and more economical than a shunt active power filter of a low VA ratio.

A practical case has been presented to check the filter performance, the compensation of a three-phase diode rectifier. Thus, the results have shown that the source current distortion is reduced from 26% to 4%in the compensated system.

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