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# Hybrid Active Power Filter for Optimization of Power Quality Improvement

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**ABSTRACT**

*Now-a-days with the improvement of technology, the demand for electric power is increasing at a growing rate. Many consumer appliances demand quality improvement in power constantly for their operation. The performance of the end user accessories dependent on the quality of power supplied. But the quality of power delivered to the consumer is affected by various factors. They are like frequency and voltage variations, faults, interruption etc. These power quality issues reduce the life time and efficiency of the equipment. The main affect caused by these problems is the presence of harmonics and interharmonics. This leads to the overheating of the equipment, insulation breakdown and over speeding of motors etc. The solution to run over these problems is to filter out these harmonics. For this purpose, there are many filters to snub harmonics but we use hybrid active filter which is combination of active series and shunt passive filter. This paper presents a control strategy for reduction of harmonics and simulation on MATLAB SIMULNK is present.*

**Keywords:** Active Filters, Passive Filters, Hybrid Filters, Power quality, nonlinear loads.

## INTRODUCTION

Electrical energy is the most efficient of energy and the modern society is dependent on the electric supply system. The life cannot be imagined without the supply of electricity. At the same time the quality of the electric power supplied is also very important for the efficient functioning of the end user equipment. The term power quality became most prominent in the power sector and both the electric power supply company and the end users are concerned about it [1-2]. The quality of power delivered to the customers depends on the voltage and frequency ranges of the power supplied. If there is any deviation in the frequency and voltage of the electric power supplied from that of the standard values, then the quality of the power delivered is affected. Now-a-days with the advancement in technology there is a drastic improvement in the semi-conductor devices. With this advancement and advantages, the semi-conductor electronic devices got a permanent place in the power sector helping to ease the control of overall system. Moreover, most of the loads are also electronic based equipment. But the semi-conductor devices are non-linear in nature and draws non-linear current from the source. And also the semi-conductor devices are involved in power conversion, which is either AC to DC or from DC to AC. This power conversion contains lot of switching operations which may introduce discontinuity in the current. Due to this non-linearity, harmonics are present which affect the quality of the power supplied to the consumer. To maintain the quality of power delivered, the harmonics should be filtered out from the power system. Thus, a device named Filter is used which serves this purpose. There are many filter topologies like active, passive and hybrid. This paper presents the use of hybrid power filters for the improvement of electric power quality problems is studied and analysed. [2]

Therefore, to overcome these drawbacks a hybrid power filter which is a combination of active and passive filters is proposed in [3]. This paper discusses how a combination of both active and passive filters is an economical solution for power quality improvement in power system. To enhance the characteristics of passive filter, the active filter should be controlled properly. The main aim of the control technique is to make active filter inject a voltage into the system that compensates the harmonics and interharmonics. To achieve this output voltage of the active filter is controlled such that it is equal to a recalculated reference value. The active filter is controlled better with instantaneous reactive power system theory. This is presented in [4] and it elaborates the different control algorithms from the formulations of instantaneous reactive power theory. Finally, it concludes that vectorial based theory yields better results with sinusoidal currents when compared with other algorithms that are used for this purpose. The control of series active in conjunction with shunt passive filter using dual instantaneous reactive power vectorial theory is presented in [5]. In this paper the proposed theory is validated by simulating it in MATLAB SIMULINK environment. The proposed control strategy is simulated for balanced load conditions.

**Advantages of Hybrid Power Filter (HPF)**

Hybrid Power Filter is a combination of series and shunt filters. Among the various available combinations, active-passive combination is effective as it has the advantages of both active and passive filters. The characteristics of the passive filter are improved [5], avoiding the problems of series and parallel resonances. The series APF with a shunt connected passive filter is widely used due to the above advantages. Thus, the control of series APF with shunt connected passive filter is studied and analysed in this paper for the improvement of electric power quality problems.

**Active Power Filters (APF)**

To overcome the drawback of passive filter, active compensation known as Active Power Filter is used recently. The APF is a Voltage Source Inverter (VSI) which injects the compensating current or voltage based on the network configuration. It was proposed around 1970. But the recent advancement in power electronics technology [2], along with the theory of instantaneous active and reactive power which was presented in 1983, APF's is an up-to-date solution with fast switching devices, low power loss and fast digital processing devices at an affordable price. Depending on the circuit configuration and function. APF is divided into two types of filters and each one is explained below. [2]

**Shunt Active Power Filter (SAPF)**

The voltage sourced inverter based Shunt APF is similar to STATCOM. It is connected in shunt at the PCC. It injects the current which is equal and opposite of the harmonic current. It acts as a current source injecting harmonics and is suitable for any type of load. It also helps in improving the load power factor. [2] The circuit diagram of the power system with shunt connected APF is shown in Fig. 2. The cost of these filters is relatively higher and so not preferred for large scale systems.

**Series Active Power Filter (SAPF)**

As the name indicates, these filters are connected in series with the line through a matching transformer. This filter injects the compensating voltage in series with the supply voltage. Thus, it acts as a voltage source which can be controlled to compensate the voltage sag/swell. These filters have their application mainly where the load contains voltage sensitive devices. [2] The circuit diagram of the power system with series connected APF is shown in Fig. 1. These filters are not used practically since they are required to handle high current ratings which increase the size of the filter as well as the losses occurring in the filter.

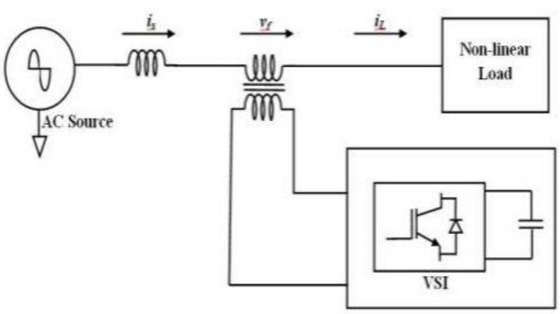



**Fig. 1 Series Active Filter [2]**

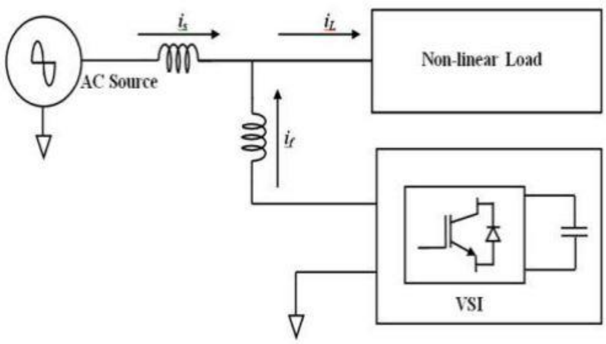



**Fig. 2 Shunt Active Filter[2]**

**Hybrid Power Filters**

The active power filters are better solution for power quality improvement of power system but they require high converter ratings. The hybrid power filters are the combination of both active and passive power filters. They have the advantage of both active and passive filters [2]. There are different hybrid filters based on the circuit combination and arrangement. They are

- Shunt Active Power Filter and Series Active Power Filter
- Shunt Active Power Filter and Shunt Passive Filter
- Active Power Filter in series with Shunt Passive Filter
- Series Active Power Filter with Shunt Passive Filter

Each filter configuration is explained below with their advantages and disadvantages.

**Shunt APF and Series APF**

This filter combination has the advantage of both series connected APF i.e., elimination of voltage harmonics and that of shunt connected APF of eliminating current harmonics. The circuit diagram is shown in Fig. 5. This combination finds its application in (FACTS). But the control of APF is complex and this combination involves two APF and hence the control of this filter configuration is even more complex. Thus, this filter combination is not used widely.

**Shunt APF and Shunt Passive Filter**

The power rating of the APF depend on the order of frequencies it is filtering out. Thus, an APF used for filtering out low order harmonics have low power rating with reduced size and cost. This logic is used in designing this filter combination. The shunt connected APF filters out the low order current harmonics while the shunt connected passive filter is designed to filter out the higher order harmonics. The circuit configuration of this filter topology is shown in Fig. 6. But the main disadvantage of this filter configuration is it cannot be suited for variable loading conditions. Since, the passive filter can be tuned only for a specific predetermined harmonic.

**APF in Series with Shunt Passive Filter**

In this filter configuration, the Active Power Filter is connected in series with a Shunt connected Passive Filter. The circuit diagram of this filter configuration is shown in Fig. 3. The advantage of this configuration is that the passive filter reduces the stress on the power electronic switches present in the APF. This filter has its application in medium to high voltage ranges.

**Series APF with Shunt Connected Passive Filter**

The Series APF and Shunt APF combination seen in Fig. 5 has the problem of complex control strategy. To run over this drawback, the shunt APF is replaced by a shunt connected passive filter. The passive power filter does not require any additional control circuit and the cost is also less. This filter combination is shown in Fig. 4. Here the series connected APF provides low impedance (almost zero) for low frequency components whereas the shunt connected APF provides less impedance for high frequency components and filters out all higher order harmonics. So this filter configuration is the most beneficial of all others and has the advantage of reducing both current and voltage harmonics. Thus [5], in this project this filter configuration is used for the improvement of electric power quality

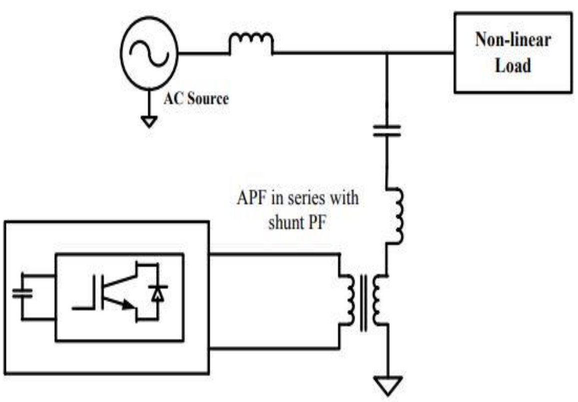



**Fig. 3 APF in series with Shunt Connected Passive Filter [2]**

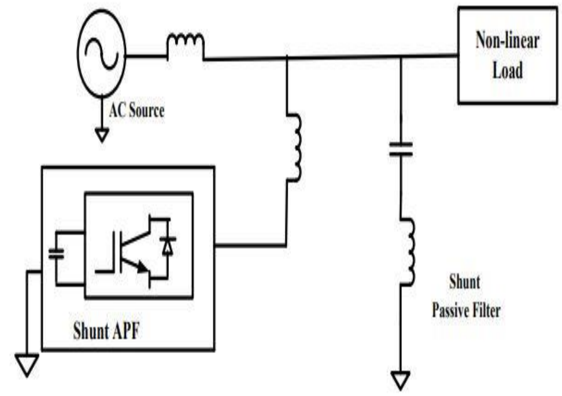



**Fig. 4 Shunt APF with Shunt Connected Passive Filter [2]**

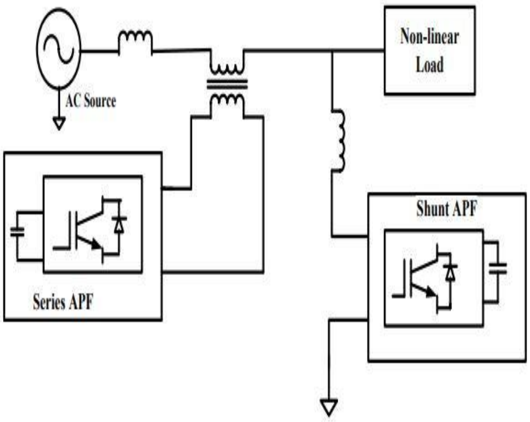



**Fig. 5. Shunt and Series APF Combination [2]**

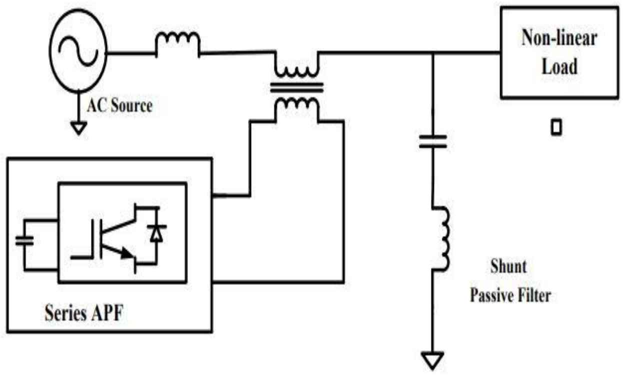



**Fig. 6. Shunt Passive and Series APF Filter [2]**

## CONTROL OF HYBRID POWER FILTER FOR PQI

The filter is used to reduce the harmonics and improve the power quality. The filter that is connected to the system should be controlled effectively such that its response characteristics are as desired. Among the different available filter configurations, hybrid power filter with series (APF) and a parallel passive filter is used in this project. The control circuit of the series connected (APF) is designed such way that the voltage injected by the APF compensates the harmonics and also enhances the performance of the shunt connected passive filter. [2] The control strategy of the hybrid power filter is explained.

**Design of Series APF**

The series APF used for the power quality improvement is realized as a Voltage Source Inverter (VSI) [8]. It can be a three-phase VSI or three single-phase VSI‟s can also be used. The VSI is connected in series with the source impedance through a matching transformer [2]. The circuit diagram is shown in Fig. 7. A capacitor is used at the input if the VSI to provide constant input voltage to VSI.

**Control Strategy**

The series APF should be controlled such that the voltage injected by it should compensate the harmonics present in the system and should help in improving the quality of power. To achieve the above purpose, the output voltage of the APF should be controlled. For this to happen, at first a reference voltage is generated which when injected by APF will serve the desired purpose. Then the actual output voltage of the series connected APF is controlled using a PI controller such that the actual output voltage generated is equal to the reference value. [2] The overall control strategy is shown by the flow chart given in Fig. 8.

**Reference Vector Generation**

To control the series connected APF the reference vector should be generated and compared with the actual voltage vector [1]. Reference vector generation is shown in Fig. 9 and fundamental current component calculation is shown in Fig. 10. The fundamental component calculation needs the grid voltage angle to calculate the value. The grid voltage angle necessary for this calculation is extracted by using a Phased Lock Loop (PLL).

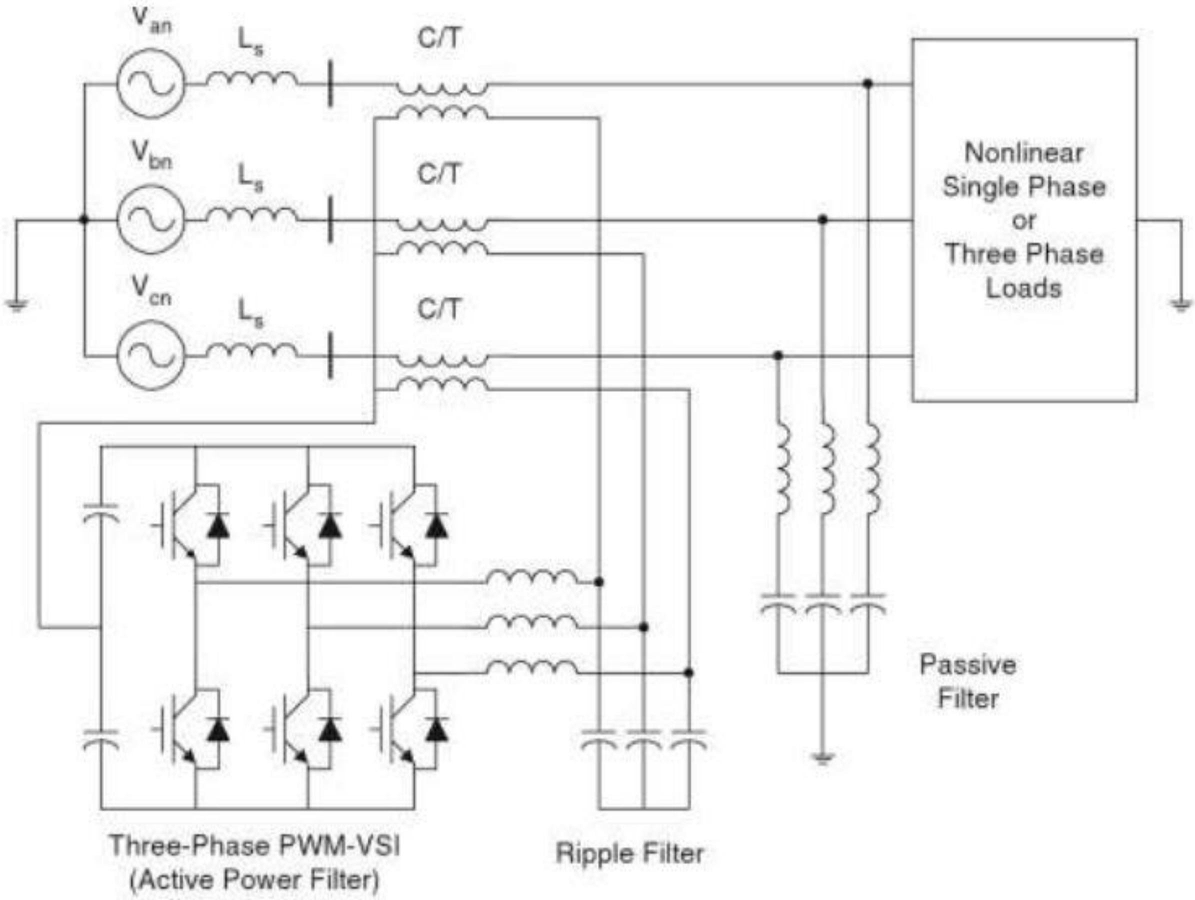



**Fig. 7 Circuit Diagram of system with hybrid filter [2]**

A Low pass filter (LPF) is used in the fundamental calculation block to filter out the harmonics and extract the fundamental component. A comparison is made between the actual and reference values of the output voltage of APF. The error is passed through a PI controller. The gain values of the controller are tuned in such a way that the error is zero and the actual value matches almost with the reference value. If this condition is achieved perfectly then the series APF improves the quality of power generated to the load by filtering out the harmonics and thus improving the performance of the system [2].

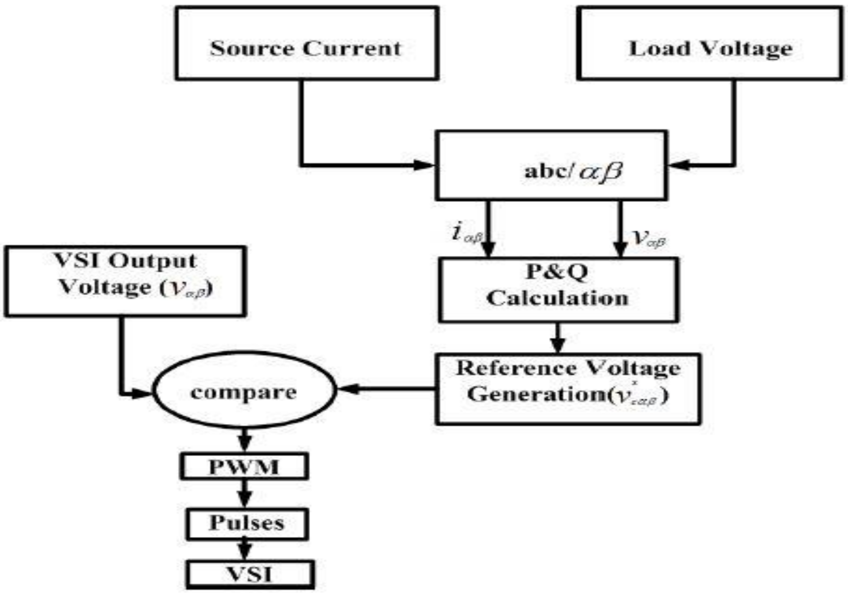



**Fig. 8 Flow Chart of Control Strategy [2]**

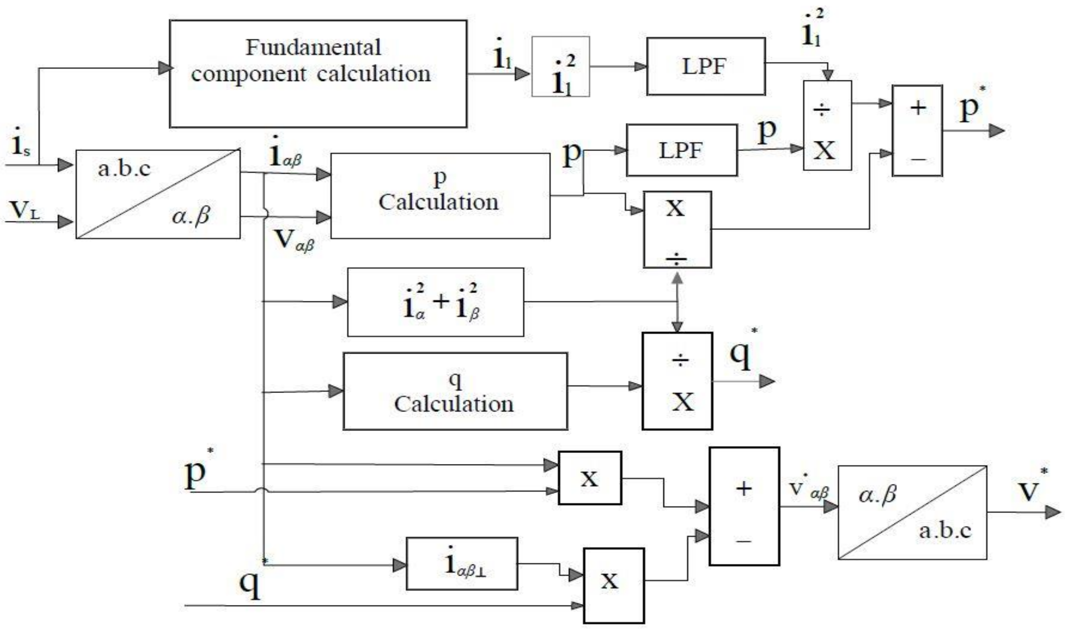



**Fig. 9 Control Block to Generate Reference Vector [2]**

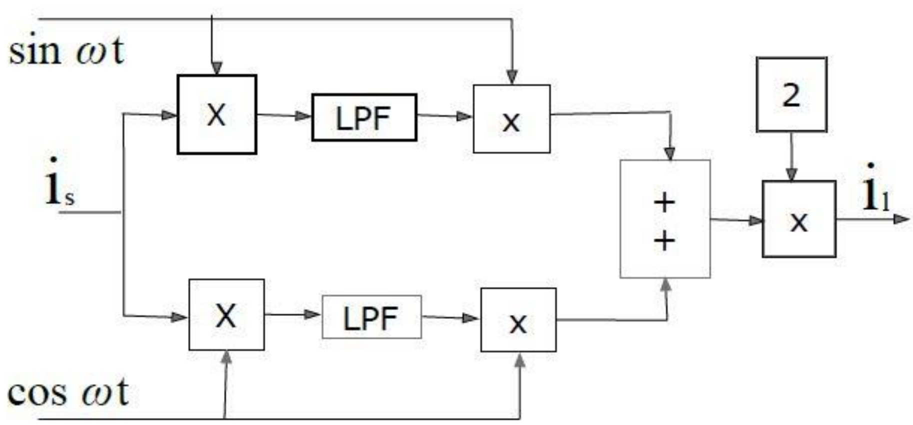



**Fig. 10 Fundamental Component Calculation [2]**

## RESULTS AND SIMULATIONS

The proposed control strategy is simulated in MATLAB SIMULINK to check the performance of the control strategy in improving the behavior of system. The simulation is carried under nonlinear balanced load. The performance of the system with the proposed control strategy with balanced load conditions is discussed in detail in the following section [2].

### Simulation Results with Balanced Load

The proposed control strategy is simulated with a non-linear balanced load and the performance of the system is analyzed. The system data is given in Table-1. The series Active Power Filter is connected through a coupling transformer whose turn's ratio is 1:1. A passive filter is connected at point of common coupling to eliminate 5th and 7th order harmonics. Also a ripple filter is also connected at the output of the Voltage Source Inverter (VSI) [2]. The values of these filters along with load values are given in Table-2.

**Table-1 System Parameters**

| System Parameter | Value |
|---|---|
| Voltage | 110 V |
| Switching Frequency | 21KHZ |
| Source Inductance | 5.7mH |
| Source Inductance | 3.7Ω |
| Turns Ratio of Coupling Transformer | 1:1 |

**Table- 2 Filter Parameters**

| Filter Parameter | Value |
|---|---|
| L5 | 13.4mH |
| C5 | 30μF |
| L7 | 6.73mH |
| C7 | 30μF |
| Lr | 13.4mH |
| Cr | 50μF |
| Rl | 30Ω |
| Ll | 50mH |
| Cl | 2200μF |

The filter impedance should be less than the system impedance for effective filtering. The simulation is carried out with nonlinear balanced load conditions of RC and RL loads.

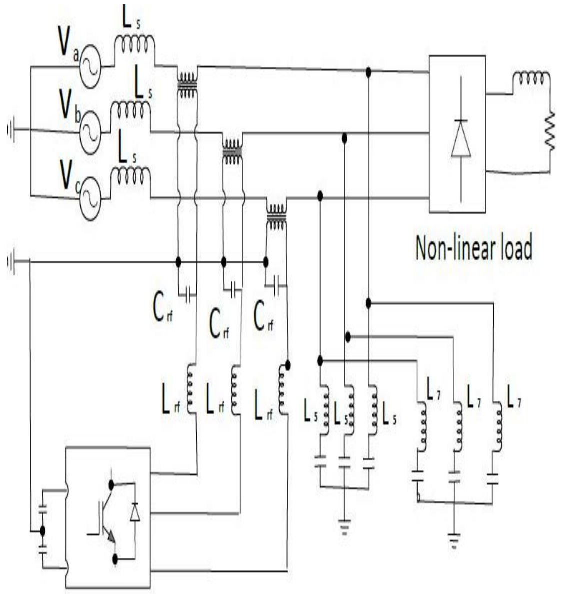



**Fig. 11 Diagram of Simulation with RL-Load [2]**

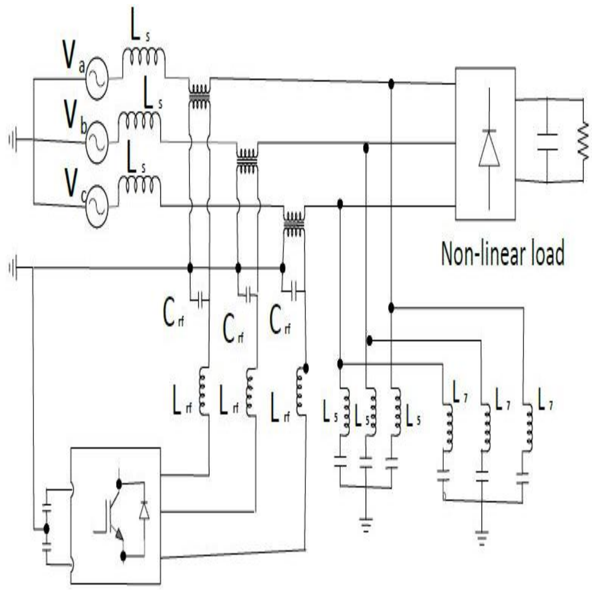
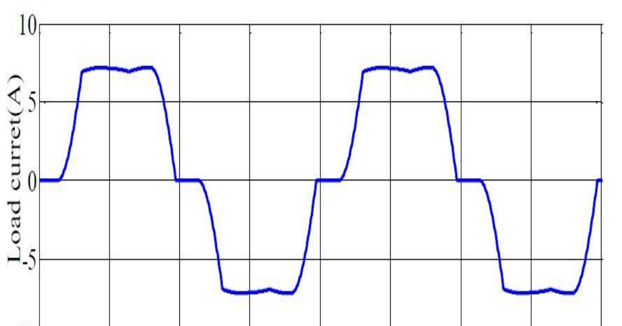
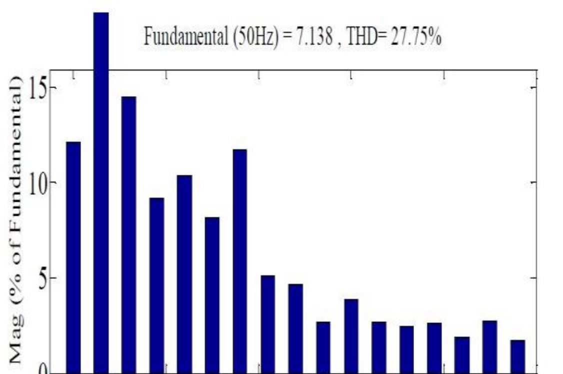



**Fig. 12 Simulation Diagram with RC-load [2]**




**(a)**

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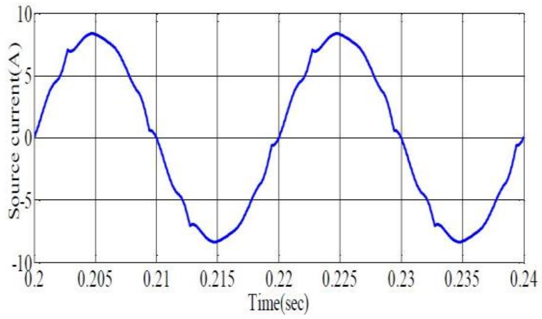


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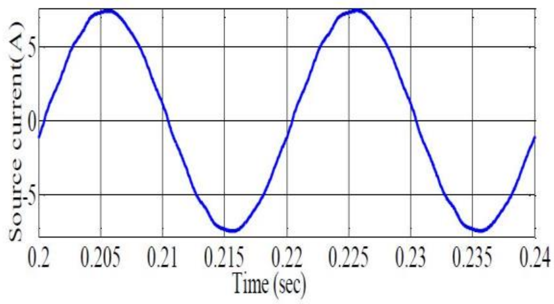


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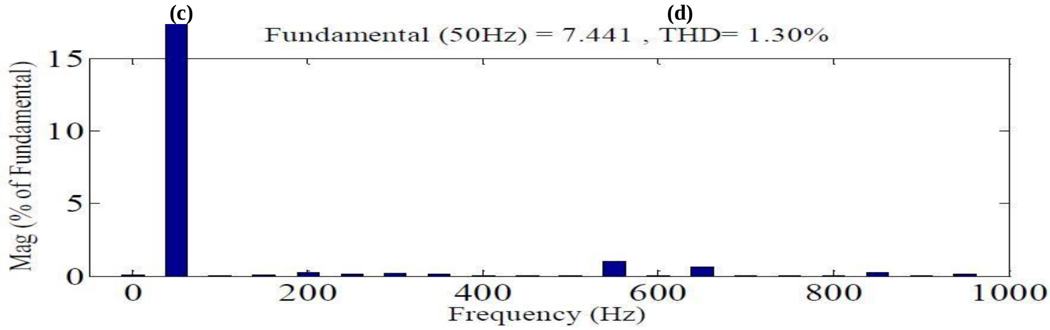
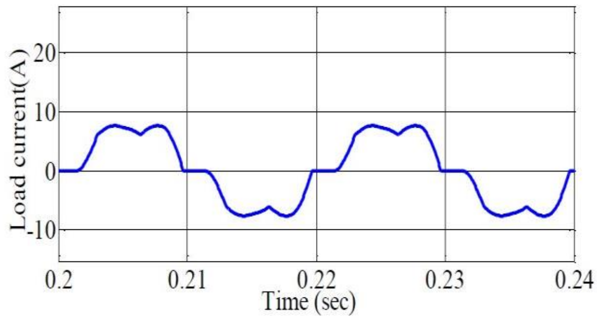
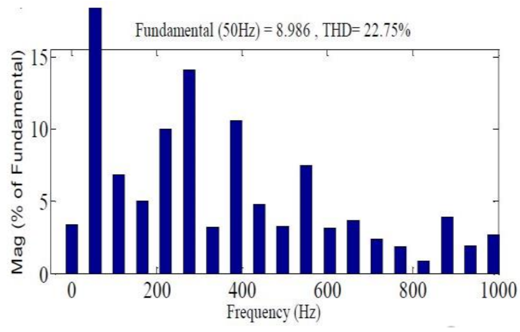



**(e)**

**Fig. 13 Simulation Results with RL Load (a) Load current without compensation (b) THD of load current (c) Source current when passive filter is connected (d) Source current when both passive and active filter are connected (e) THD of source current when both filters are connected [2]**




**(a)**

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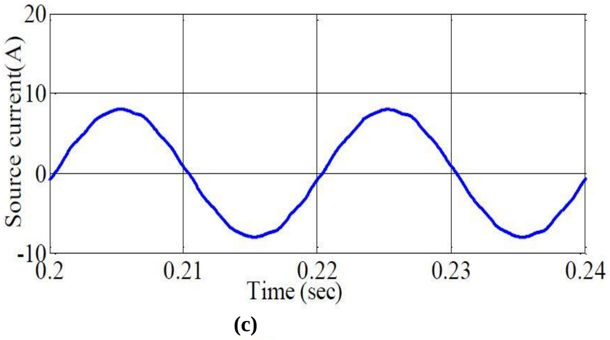


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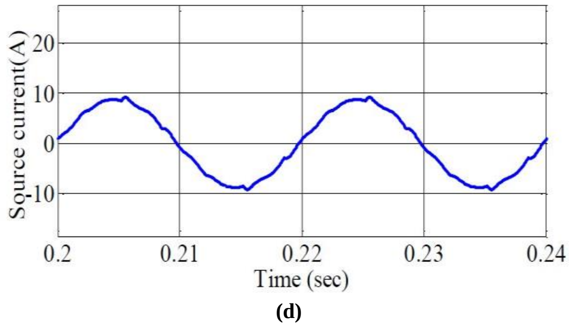


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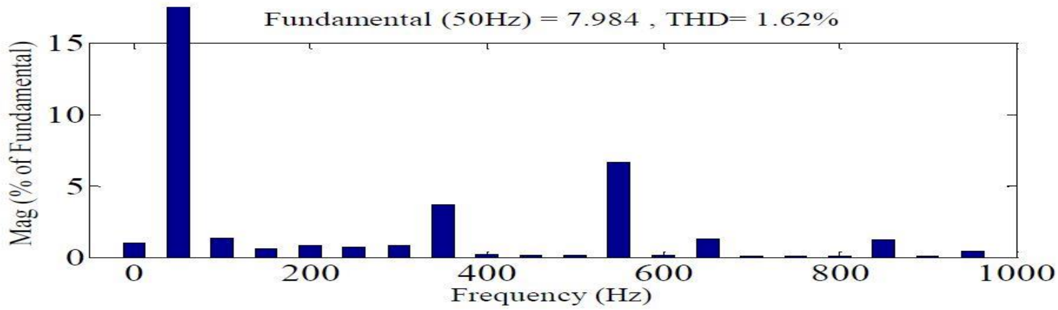


**(e)**

**Fig. 14 Simulation Results with RC Load (a) Load current without compensation (b) THD of Load current without compensation (c) Source current when passive filter is connected (d) Source current when both passive and active filter are connected (e)THD of) Source current when both passive and active filter are connected [2]**

## CONCLUSION

The demand for electric power supply is increasing at an exponential rate and at the same time the quality of power delivered became the most outstanding issue in the power sector. Thus, the reduction of harmonics and improving the power factor of the system is very important. This paper presents a solution to improve the electric power quality by the use of APF is discussed. Most of the loads connected to the system are non-linear which is the major source of harmonics is in the power system. The non-linear load draws non-linear current from the supply. Thus the voltage at point of common coupling is characteristics in addition to improve the system performance. The active power filter works well with variable loads even and improve the power factor of the system. The simulation is also carried out with balanced load and found that the active power filter improves the system behavior by reducing the harmonics. Therefore, it is concluded that the hybrid filter consisting of series APF and a shunt passive filter is a feasible economic solution for improving the power quality problems in electric power system. To compensate the load harmonics a filter is connected at the point of common coupling which injects the compensating current. To achieve this Hybrid power filter with series connected active power filter and shunt connected passive filter is used. The APF is controlled based on the Dual Instantaneous Reactive Power Theory to compensate the load harmonics. Simulation of the proposed control strategy show the behavior of active power filter under different operating conditions. [2]

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