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# Harmonic Mitigation in a Single Phase Non-Linear Load Using SAPF with PI Controller

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***Abstract***
Power Quality is a major consideration in all office equipments, industries and residential home appliances. Harmonics play a vital role in power quality issues. A harmonic is generated and deteriorating the quality of power due to non-linear load, which is connected to the electrical system. Based upon the load, there will be an increase in harmonic voltage and currents in the system, which will affect the whole system. The limitations for harmonic voltages and harmonic currents have defined in IEEE 519 and IEC standards. That limitation can be achieved by using shunt Active Power Filters. This paper deals on shunt active power filter with PI controller. Shunt active power filter (SAPF) is designed by employing voltage source inverter with pulse width modulation (PWM). For R-L non linear load this harmonic mitigation is done. The MATLAB / SIMULINK model of this system is simulated and results are obtained through THD analysis.
**Keywords**: Harmonics, Non-linear load, PI controller, Shunt Active Power Filter (SAPF).

## I. INTRODUCTION

System performance can be achieved by using a controller to convert and control power to nonlinear loads. The non-uniform sinusoidal current waveform was obtained by harmonics generated in the voltage source. The distortion in voltage and current will affect the total system efficiency. These will lead to damage to the system components and failure of the system. Non-linear loads create harmonic distortion. These harmonic distortions can be eliminated using harmonic filters. There are three types of harmonic filters; they are passive, active and hybrid filters. The selection of filter is based upon the problem.

A Passive filter is designed with only inductors, capacitors and resistors, so that it is less expensive. Based on the harmonic source present the design of passive filter will change accordingly. Active filters are easy to tune, and they are small with less weight and can produce a high gain. Active filters contain power electronic devices so that harmonics can be distorted easily. In this paper, single phase active filter is used to reduce the harmonics which are present in the system [1], [2].

## II. HARMONICS

Harmonics are integral multiples of some fundamental frequency that, when added together result in a distorted waveform [4].

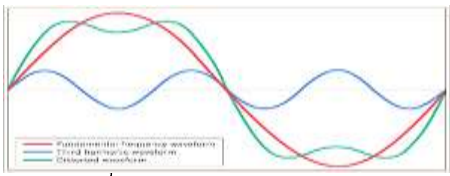

**Fig 1.** *3rd Harmonic distorted waveform*

The sinusoidal voltage source supplies smooth sinusoidal waveform, but nonlinear loads will lead to distorted waveform [2].

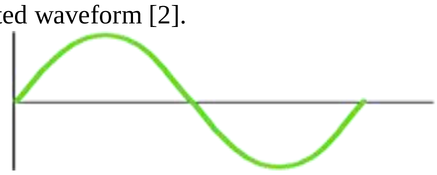

**Fig 2.** *Pure sinusoidal waveform*

**Fig 3**. Harmonic distorted waveform

## III. FILTERS

### A. Passive Filters

The passive filters are used in order to protect the system by reducing the harmonic current to enter the power system. The most common type of shunt passive filters used in harmonic reduction is the single tuned filter (STF) which is either a low pass or band pass filter [1], [2]. This type of filter is the simplest form to design and less expensive.

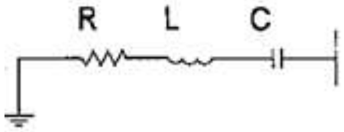


**Fig 4**. Single Tuned Filter

The double tuned filter (DTF) can be used to filter two harmonic sources simultaneously. DTF has a few advantages such as only one reactor is subjected to full- line voltage and smaller space needed.

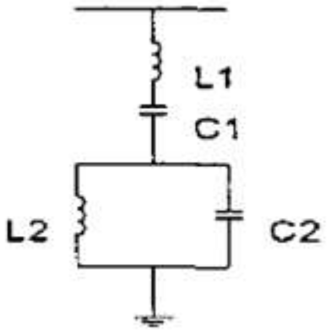


**Fig 5**. Dobule Tuned Filter

### B. Active Filters

It is made up of OP-Amps, resistors and capacitors. Active filters are easy to adjust over a wide frequency range without altering the desired response. High input impedance prevents excessive loading of the driving source, and low output impedance prevents the filter from being affected by the load. The active filters are used in a condition where the harmonic orders change in terms of magnitudes and the phase angles. In such conditions, it is feasible to use the active elements instead of passive ones in order to provide dynamic compensation [2], [3], [4]. There are three types of configurations; they are series active filter, shunt active filter and hybrid filter.

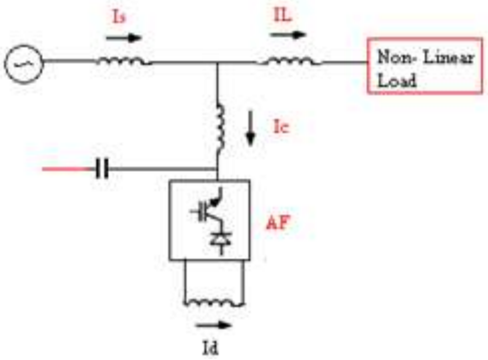


**Fig 6**. Current fed type AF

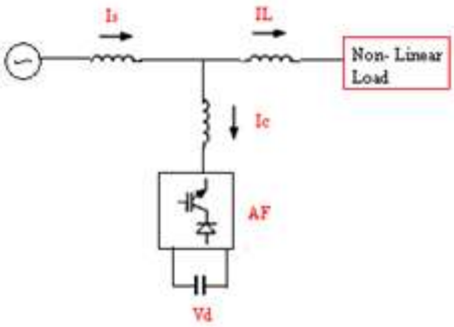


**Fig 7**. Voltage fed type AF

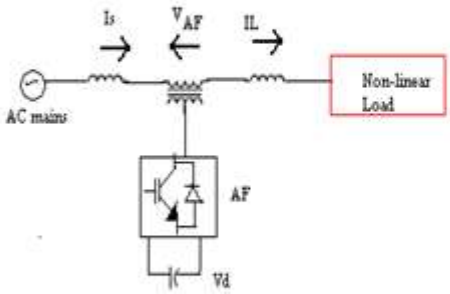


**Fig 8**. Series Type AF

Active filters can be used with passive filters improving compensation characteristics of the passive filter and avoiding the possibility of the generation of series or parallel resonance in the power system. The combination of both active and passive filter is known as a hybrid filter [1].

## IV. SELECTION OF FILTERS

Fig.9 gives a proper selection of active filter for all power quality disturbances. Since nowadays many industries are manufacturing active filters [1], [2].

| S.no | Compensation for particular Application | Active Series | Active Shunt | Hybrid of Active Series and Passive Shunt | Hybrid of Active Shunt and Active Series |
|---|---|---|---|---|---|
| 1 | Voltage Harmonics | XXX | | XX | X |
| 2 | Current Harmonics | | XX | XXX | X |
| 3 | Current harmonics & Reactive power | | XXX | XX | X |
| 4 | Current harmonics, Reactive power & Load Balancing | | XX | | X |
| 5 | Current harmonics, Reactive power, Load Balancing & Neutral Current | | X | | |
| 6 | Voltage Harmonics & Voltage Regulation | XX | | | X |
| 7 | Voltage Harmonics, Voltage Regulation, Voltage Flicker & Voltage Sag & Dips | XX | | | X |
| 8 | Current Harmonics & Voltage Harmonics | | | XX | X |
| 9 | Current Harmonics, Reactive Power, Voltage Harmonics, Voltage Regulation | | | X | XX |
| 10 | Current Harmonics, Reactive Power & Voltage Balancing | | XX | X | |
| 11 | Current Harmonics & Load Balancing | | X | | |
| 12 | Current Harmonics, Neutral Current | | X | XX | |

**Fig 9**. Selection of Filters for Harmonic

AF Configuration with higher number of "X" is more preferred

## V. CONTROL SCHEME

It contains two main components, Fig.10 show that they are power electronic controller and PI Controller. The power Electronic controller is nothing, but a voltage type inverter which uses a capacitor with a regulated DC voltage [5]. PI Controller is used for determining the desired reference signal, and generating the gating pulse to active shunt filter [4], [5].

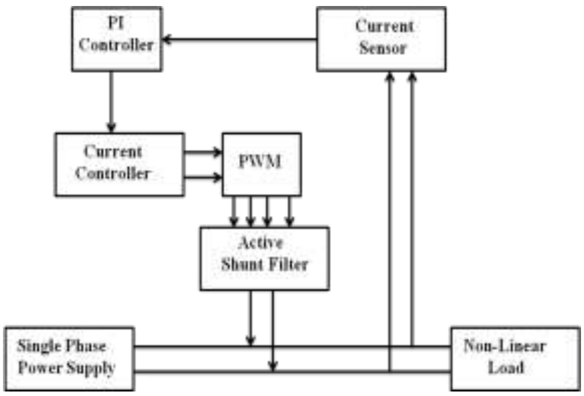


**Fig 10**. Block diagram

## VI. Simulation

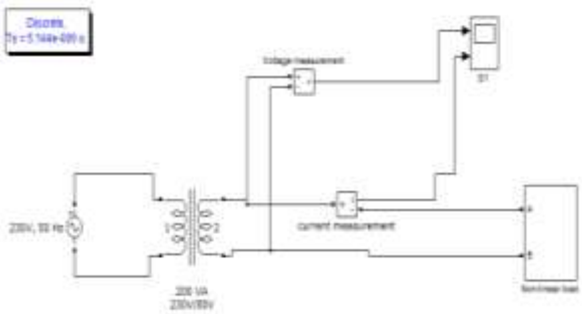

**Fig11**. Single Phase Non-linear load circuit

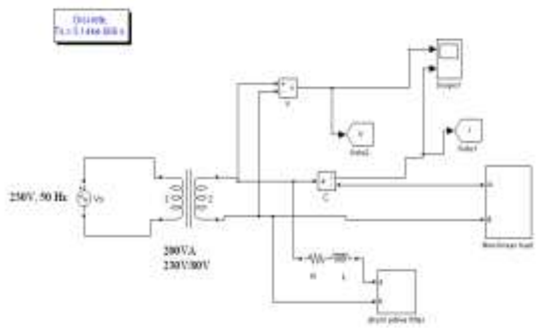

**Fig 12**. Non-linear load with SAPF and PI Controller

***Table 1.****System Parameters*

| COMPONENTS | RANGE |
|---|---|
| **Line Voltage** | **230 V, 50 Hz** |
| **Non-Linear Load** | **10Ω, 100mH, 10Ω, 100mH** |
| **Filter impedance** | **1Ω, 2.5mH** |
| **DC side capacitance** | **1400μf** |
| **Power Converter** | **4 IGBT** |

The Table.1 shows that The non-linear load consists of an AC-DC rectifier, and is designed using an IGBT with two RL load which are connected parallel where R1 and R2 are 10 ohms and L1 and L2 are 100mH.

## VII. RESULTS

I have used FFT analysis to measure the THD of Load current and voltage before and after applying the filter from the circuit fig.11 and fig.12.[6], [7].

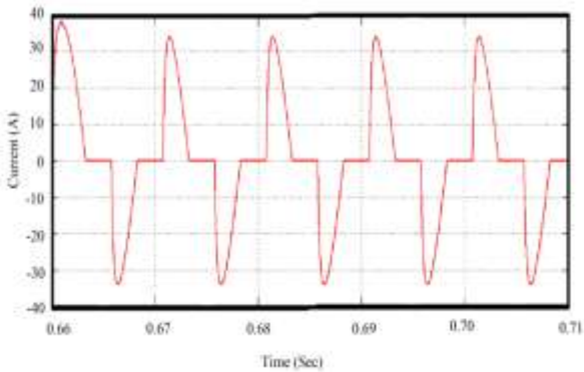


**Fig13.** Output waveform of load current without SAPF and PI Controller

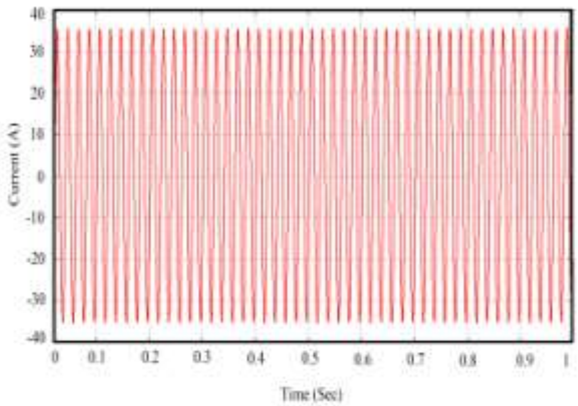


**Fig14.** Output waveform of load current with SAPF and PI Controller

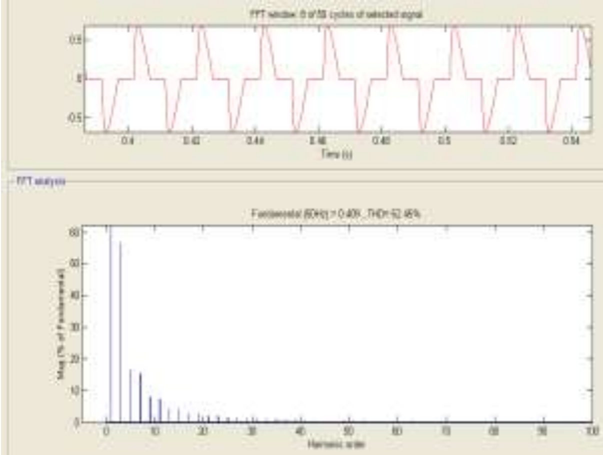

**Fig 15.** Load current THD using FFT analysis without SAPF and PI controller

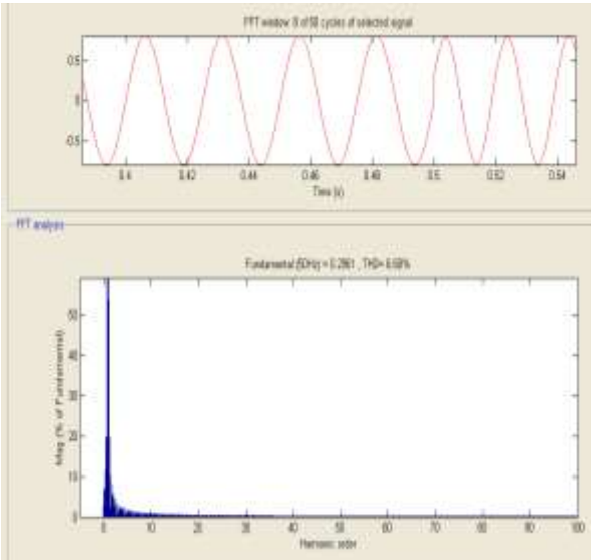

**Fig 16.** Load current THD using FFT analysis with SAPF and PI Controller

Fig.13 shows the non-linear load current without SAPF and PI Controller. In Fig.15 the total current harmonic distortion is 62.45 % of the fundamental [6], [7] and [8].

Fig.14 shows the non-linear load current with SAPF and PI Controller, and in Fig.16 the total current harmonic distortion is reduced to 6.68 %.Reduction in current harmonic orders is given below in Table.2.

***Table 2.****THD table for current harmonic mitigation*

| **Funda-mental har-monic** | **% of THD Before mitigation 62.45 %** | **% of THD After mitigation 6.68%** |
|---|---|---|
| **H3** | **56.58** | **0.98** |
| **H5** | **16.81** | **1.75** |
| **H7** | **15.28** | **0.40** |
| **H9** | **7.84** | **0.83** |
| **H11** | **7.22** | **0.57** |
| **H13** | **4.38** | **0.27** |

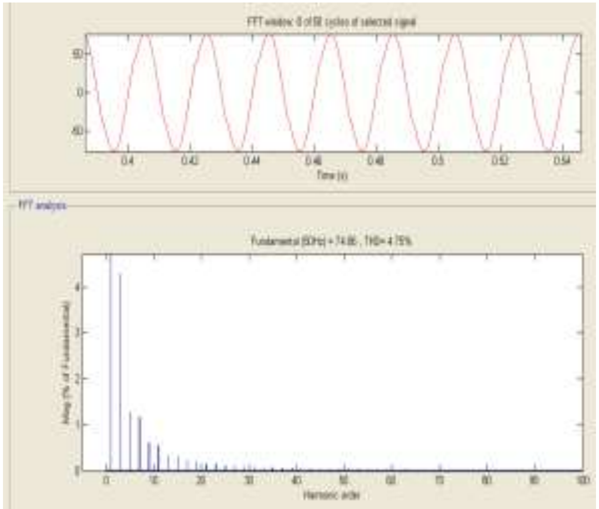

**Fig 17.** Load voltage THD using FFT analysis without SAPF and PI controller

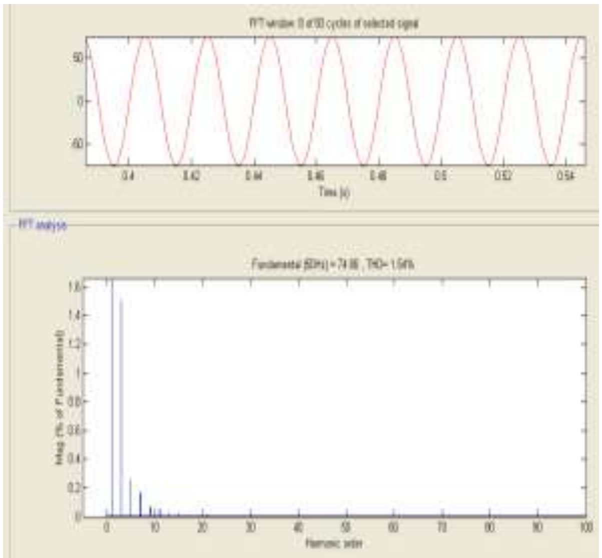

**Fig 18.** Load voltage THD using FFT analysis with SAPF and PI controller

Fig.17 shows that the non-linear load voltage THD without SAPF and PI controller is 4.75 % of the fundamental harmonics [6], [7] and [8].

Fig.18 shows the non-linear load voltage THD with SAPF and PI controller is reduced to 1.54 %. Reduction in voltage harmonic orders is given below in Table.3

***Table 3.****THD table for voltage harmonic mitigation*

| **Fundamental harmonic** | **% of THD Before mitigation 4.75 %** | **% of THD After mitigation 1.54%** |
|---|---|---|
| **H3** | **4.30** | **1.51** |
| **H5** | **1.28** | **0.26** |
| **H7** | **1.16** | **0.17** |
| **H9** | **0.60** | **0.07** |
| **H11** | **0.55** | **0.05** |
| **H13** | **0.33** | **0.03** |

## VIII. Conclusion

Thus, a single phase shunt active power filter with PI controller is used for reducing the current harmonics and voltage harmonics in the non-linear load. Single phase electrical systems, where the non-linear load can be a high speed printer or DC Motor or Induction Motor any other industrial equipment. This proposed control scheme will be very effective in harmonic mitigation.

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