

# Analysis on power quality improvement for non linear loads by harmonic reduction using different techniques

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## Abstract

*Power Quality improvement always becomes a challenge for power system engineers.. Harmonics play significant role in deteriorating quality of power. Harmonic distortion in electric distribution system is increasingly growing due to the widespread use of nonlinear loads in industries such as variable Speed Drives. Large considerations of such loads raise harmonic voltage and currents in an electrical system to unacceptable high levels that can adversely affect the system. IEEE standards have defined limits for harmonic voltages and harmonic currents. Various power filters have been considered a potential candidate to bring these harmonic distortions within the IEEE limits. In this paper Performance analysis of Shunt active power filter (SAPF) is analysed for various types of non-linear loads. Among the various control schemes available for SAPF, indirect current control scheme is used here. A voltage source inverter with pulse width modulation (PWM) is employed to form the Active Power Filter. A vector controlled variable Speed Drive is considered as nonlinear load on ac mains for the elimination of harmonics by the proposed schemes. MATLAB model of the various schemes are simulated and obtained results are studied and compared.*

## Keywords

*APF-active power filter, Variable speed drive, PWM controller, Hybrid filter, THD-total harmonic distortion.*

## 1.Introduction

The variable speed drives are extensively used in almost all areas of industry and utility services such as material handling plants, transportation systems, tracking systems, manufacturing processes, cement mills, rolling mills, robots, CNC machines, pumps, fans, compressors etc., The de-facto industrial standard necessitates the drive to have swift torque & speed response, four quadrant operation capability, high torque-to-weight ratio in addition to the overall economy.

With the advances in power electronics, especially the development of voltage source inverters, which can provide variable voltages at variable frequencies, induction motors are also being used as variable

speed drives. The 3-phase induction motors are most preferable for drive applications because of their ruggedness, smaller size and low cost.

This work presents a method capable of designing power filters to reduce harmonic distortion. The proposed method minimizes the designed filters' total investment cost such that the harmonic distortion is within an acceptable range. Among the type used are active filters which block low harmonics such as 3rd, 5th, 7th order and etc harmonics and also harmonics of higher order with large frequency range. There are two types of filters that are usually used, passive and active filters. This project focuses on analysis using PI Voltage Controller based active power to eliminate harmonics.

Calculations are a major part of design process in all aspects of engineering applications. This laborious and time consuming process can be made really easy by the aid of high level engineering software, i.e MATLAB.

## A. Harmonics and harmonic order

Harmonics are the integer multiples of the fundamental frequency of any periodical waveform are called e.g.

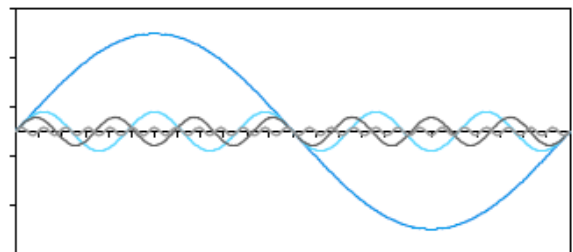


Figure 1 Harmonics and harmonic orders

Acoustic waves  
Electrical 'waves'

For power networks, 50 Hz (60 Hz) is the fundamental frequency and 150 Hz (180 Hz), 250 Hz (300 Hz) etc. are higher order harmonics viz. 3rd & 5th

=> Odd Harmonics (5th, 7th....)  
 => Even Harmonics (2nd, 4th ....)  
 => Triplen Harmonics (3rd, 9th, 15th ..)  
 Non-integer multiples of the fundamental frequency of any periodical waveform are called Inter-harmonics e.g. 2.5th => 125 Hz at 50 Hz base

### B. Harmonic distortions

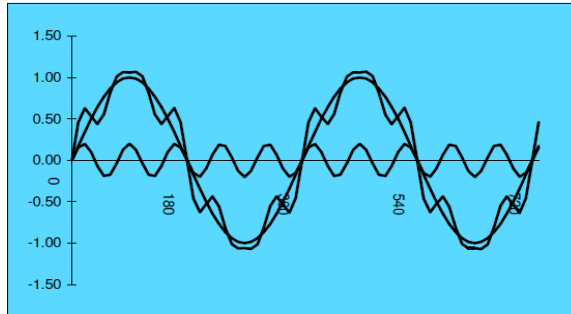


Figure 2 Harmonics distortions

### C. Harmonics representations

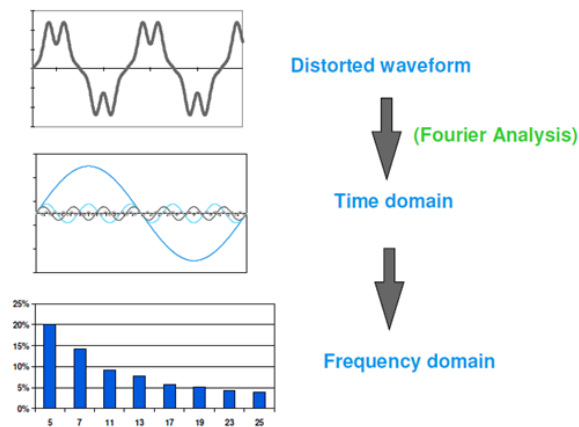


Figure 3 Harmonics representation

### D. Where do the harmonics come from

Non-linear loads such as:  
 Variable speed drives, Uninterruptible power supplies (UPS), Industrial rectifiers, Welding machines, Fluorescent lighting systems (electronic ballast), Computers, Printers, Servers, Electronic appliances.

### E. Reducing harmonics

Structural modification  
 Improved internal filtering (chokes)  
 12 or more pulse drive  
 Controlled active rectifier  
 Strengthen supply etc  
 External Passive Filter  
 Capacitor + series reactor

### External Active Filter

#### Active harmonic filter Technology

#### F. Introduction to electrical drives

Whenever the term electric motor or generator is used, we tend to think that the speed of rotation of these machines are totally controlled only by the applied voltage and frequency of the source current. But the speed of rotation of an electrical machine can be controlled precisely also by implementing the concept of drive. The main advantage of this concept is, the motion control is easily optimized with the help of drive. In very simple words, the systems which controls the motion of the electrical machines, are known as electrical drives. A typical drive system is assembled with a electric motor (may be several) and a sophisticated control system that controls the rotation of the motor shaft. Now a days, this control can be done easily with the help of software. So, the controlling becomes more and more accurate and this concept of drive also provides the ease of use. This drive system is widely used in large number of industrial and domestic applications like factories, transportation systems, textile mills, fans, pumps, motors, robots etc. Drives are employed as prime movers for diesel or petrol engines, gas or steam turbines, hydraulic motors and electric motors.

#### Advantages

- Flexible control characteristic – This is particularly true when power electronic converters are employed where the dynamic and steady state characteristics of the motor can be controlled by controlling the applied voltage or current.
- Available in wide range of speed, torque and power.
- High efficiency, lower noise, low maintenance requirements and cleaner operation.
- Electric energy is easy to be transported.

A typical conventional electric drive system for variable speed application employing multi Machine system. The system is obviously bulky, expensive, inflexible and require regular maintenance. In the past, induction and synchronous machines were used for constant speed applications – this was mainly because of the unavailability of variable frequency supply.

With the advancement of power electronics, microprocessors and digital electronics, typical electric drive systems nowadays are becoming more compact, efficient, cheaper and versatile this is shown in Figure 4. The voltage and current applied to the motor can be changed at will by employing power

electronic converters. AC motor is no longer limited to application where only AC source is available, however, it can also be used when the power source available is DC or vice versa.

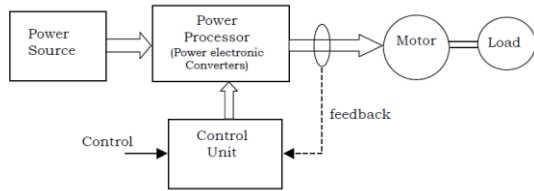


Figure 4 Advanced electric drive system

## 2. Shunt active power filter with non-linear load

Shunt active filter is used in the load side of the system. Because non-linear loads is to generate harmonics in the current waveform.

### A. Basic concept of active power filter

Figure 5 shows the configuration of active power filter with non-linear load. The basic operating principle of active power filter is that a non-sinusoidal waveform at a bus can be corrected to sinusoidal by injecting current of proper magnitude and waveform.

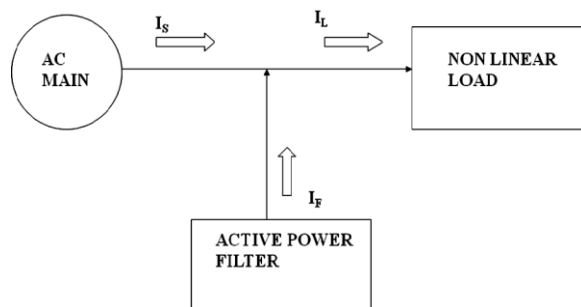


Figure 5 Basic concept shunt active filter

The basic concept of APF is explained in fig

$$I_L = I_S + I_F \quad (1)$$

The load current having fundamental and harmonic content,

and  $I_F$  is the harmonic compensating current.

$$I_L + I_H = I_S + I_H \quad (2)$$

Filter provide harmonic requirement of the load

$$I_L + I_H = I_S + I_H \quad (3)$$

$$I_L = I_S \quad (4)$$

Thus the supply current represents the fundamental waveform input output harmonics. Figure 6. shows the configuration of active shunt filter with non-linear

load and the full bridge converter. which is almost widely used to eliminate current harmonics, reactive power compensation and balancing the unbalanced currents.

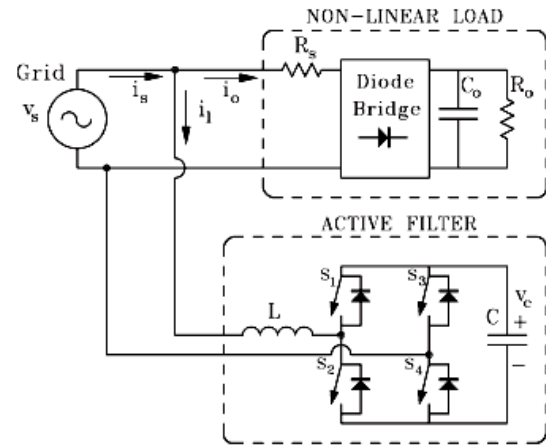


Figure 6 Shunt APF with non-linear load and the full-bridge Converter

### B. Non-linear loads

Non-linear loads are considered as the second category of loads. The application of sinusoidal voltage does not result in a sinusoidal flow applied sinusoidal voltage for non-linear devices. In this system the nonlinear load consists of a diode bridge, a series resistance ( $R_s$ ), a load resistance ( $R_o$ ) and a load capacitance ( $C_o$ ), Induction motor load, and DC motor load.

### 3. Control scheme

Figure 7 shows the control scheme for the APF system. DC bus voltage and supply voltage and current are sensed to control the APF [1]. The sensed dc bus voltage of the APF along with its reference value are processed in the P-I voltage controller. The truncated output of the P-I controller is taken as peak of source current. A unit vector in phase with the source voltage is derived using its sensed value. The peak source current is multiplied with the unit vector to generate a reference sinusoidal unity power factor source current. The reference source current and sensed source current are processed in hysteresis carrier less PWM current controller to provide gating signals for the MOSFETs of the APF. In response to these gating pulses, the APF impresses a PWM voltage to flow a current through filter inductor to meet the harmonic components of the load current. Since all the quantities such as dc bus voltage etc. are symmetric and periodic corresponding to the half cycle of the ac source. A corrective action is taken in

each half cycle of the ac source resulting in fast dynamic response of the APF.

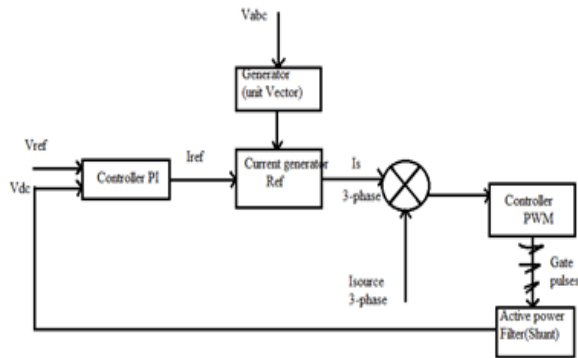


Figure 7 Control scheme for APF system

### 4.Simulation

Non-linear Speed Drive load is simulated along with various filter schemes. First a simple system is shown in which three phase ac supply is connected to variable Speed Drive as shown in a Figure 8. Thus a harmonic analysis has been done on it. In next step the simulation model is connected with shunt active power filter as shown in Figure 9. The internal filter model is shown in Figure 10 where the control mechanism or PWM is employed to generate gate signals using PI controller. Figure 11 shows a simulink model of a drive system connected to a hybrid filter in shunt. A hybrid filter comprises of a passive filter branch connected to active filter.

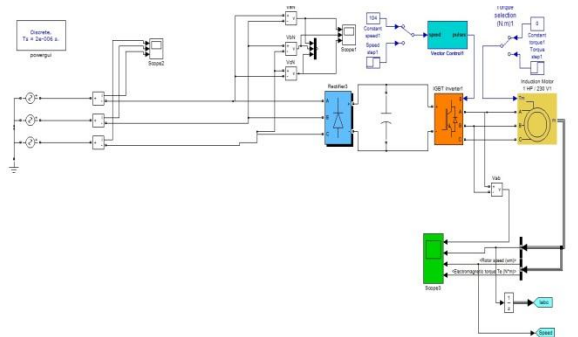


Figure 8 Simulation model when connected without any filter

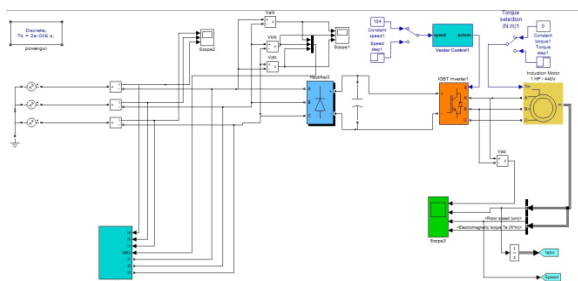


Figure 9 Simulation model with Shunt APF

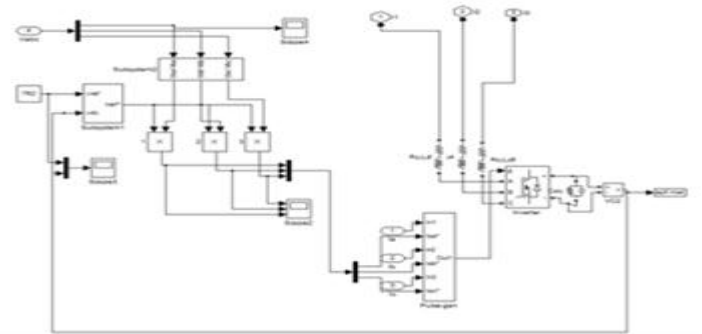
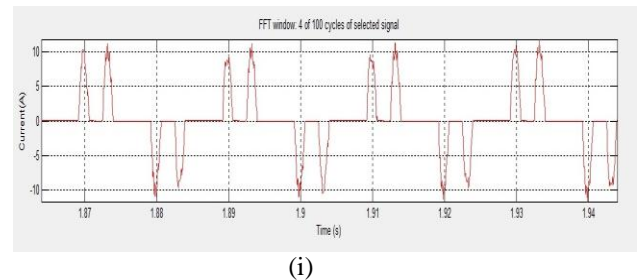


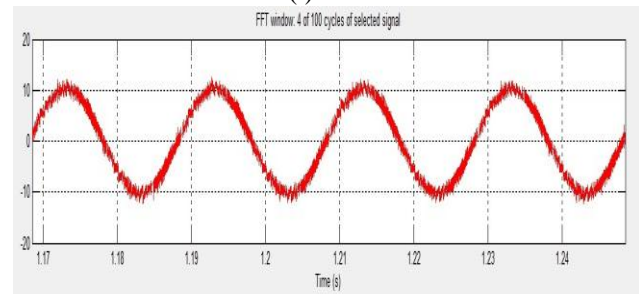
Figure 10 Shunt APF model with PI controller

### 5.Simulation results

A FFT analysis has been performed on various filtration schemes with different motor speeds

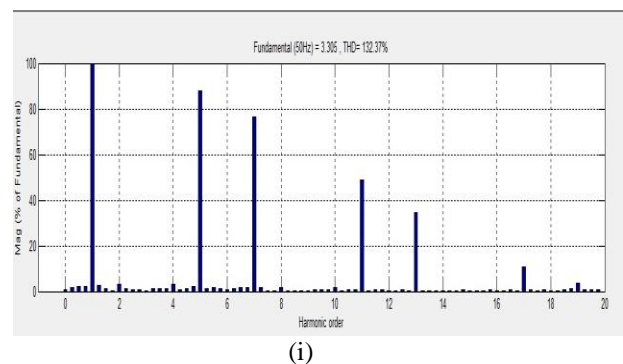


(i)

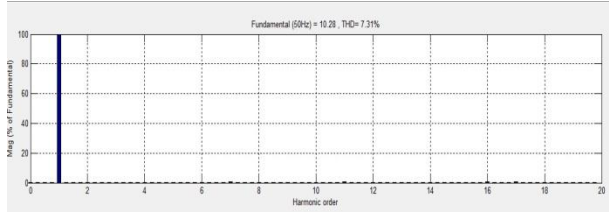


(ii)

Figure 11 Current waveform at 78 rad/sec for (i) no filter (ii) shunt active filter



(i)



(ii)

Figure 12 Harmonic analysis at 78 rad/sec for (i) No filter (ii) shunt active filter

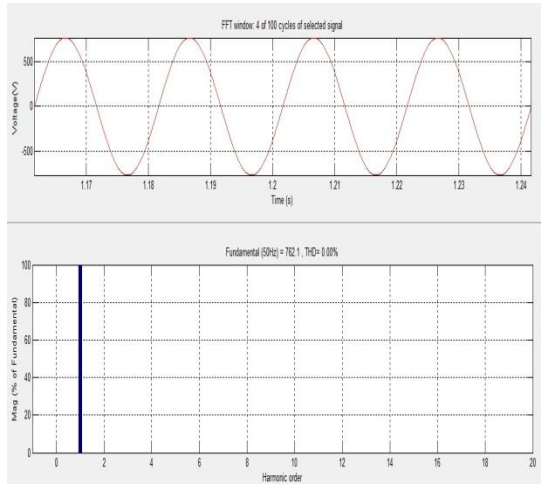


Figure 13 Voltage waveform and THD with no filter at 78 rad/sec

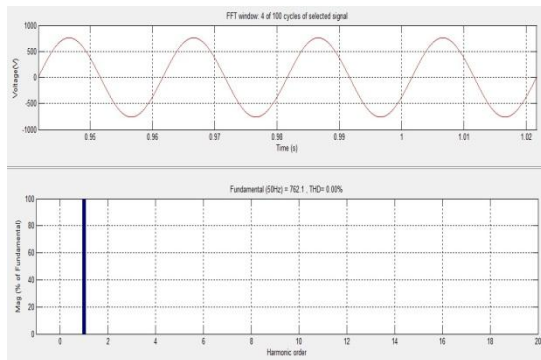
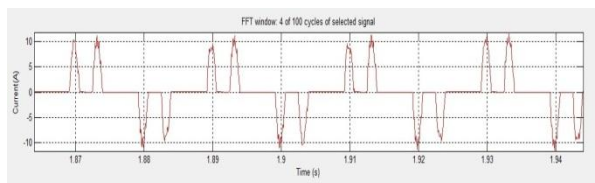
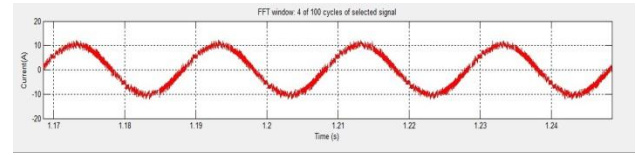


Figure 14 Voltage waveform and THD with active filter at 78 rad/sec.

The same observations were done at 104 rad/sec

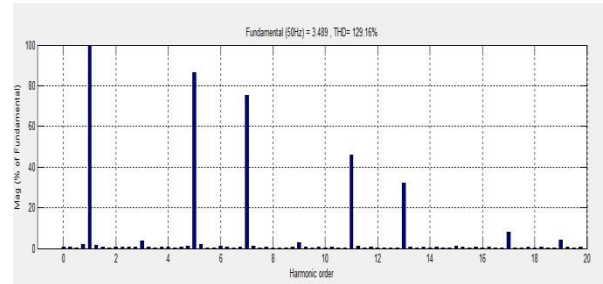


(i)

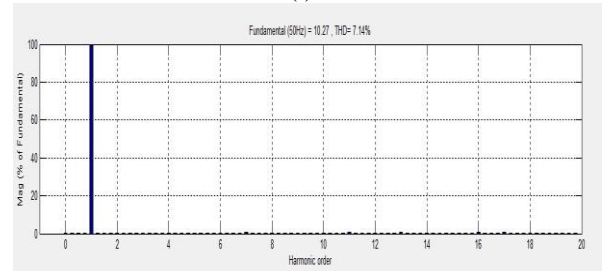


(ii)

Figure 15 Current waveform at 104 rad/sec for (i) No filter (ii) active filter

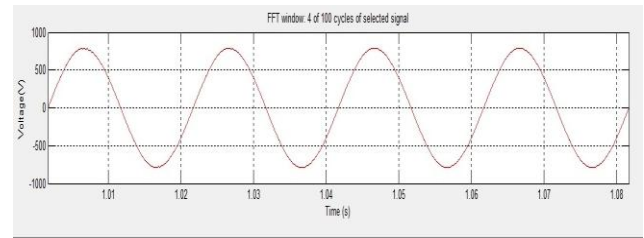


(i)



(ii)

Figure 16 Current THD at 104 rad/sec for (i) No filter (ii) active



(ii)

Figure 17 Voltage waveforms at 78 rad/sec for Active

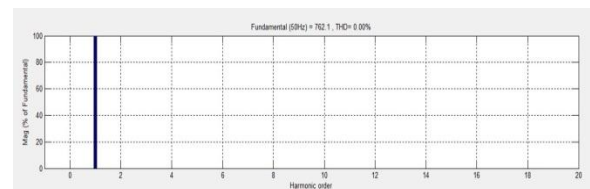


Figure 18 Voltage THD at 104 rad/sec for Active filter

## 6. Summary

Table 1 Summary of all the results

S . N	Speed (rad /s)	Filter Used	Current THD	Voltage THD	Current THD Improvement	Voltage THD Improvement
1	78	No filter	139.37%	0.00%	-----	-----
2	78	Active filter	7.31%	0.00%	132.06%	0.00%
3	104	No filter	129.16%	0.00%	-----	-----
4	104	Active filter	7.14%	0.00%	122.02%	0.00%

## 7. Conclusion

In this paper harmonic analysis and its suppression techniques were implemented using a simulation model with variable Speed Drive load. Figure 15 and 16 shows the input end current in presence of no filter and active filter at 78 rad/sec. motor speed. It has been observed that there is no voltage distortion when no filter scheme is employed and same with the active filter scheme. Figure 17 and 18 shows the current waveforms and THD respectively of all three schemes. It has been seen that the percentage THD gets reduced with increase in speed of the motor connected at load end. Table 1 gives a brief summary of the experiments performed to eliminate harmonics. So it is concluded that PI controller based active filters can reduce the current percentage THD to around 7% with no voltage harmonics. The more improved results can be achieved with the implementation of hybrid filters and other control techniques so that, the current and voltage THD could reach below 1% and within IEEE 519 standard limits.

## Appendixes

### Circuit Parameters

V=440V, Frequency=50Hz

Active filter-

Rc= 0.1 ohm, Lc= 2mH

Cdc=4700microF, CL=500microF

Vdc=Vref= 762V

Hybrid filter-

Ra=0.25ohm, La=2.5mH

5<sup>th</sup> – L=6.22mH, C= 65microF

7<sup>th</sup> – L=3.17mH, C= 65microF

Cr= 6.75 microF, Lr= 6 mH

Motor- 440V, 50 Hz, 3 Phase squirrel cage induction motor.

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