

Prof. D Venkatramanan
EN662 Mini-project report

Single-phase active filter for harmonic compensation

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Abstract:

In the modern power distribution system, majority of loads draw reactive power and/or harmonic currents from ac source along with main active power currents. These non-unity power factors linear and non-linear loads cause low efficiency of supply system, poor power factor, destruction of other equipment due to excessive stresses and EM1 problems. Active filters have been considered an effective solution to reduce these problems. This paper provides an Active Power Filter (APF) based on simple control techniques to provide reactive power and harmonics compensation for linear and non-linear single-phase loads. A voltage source inverter with carrier less hysteresis, PWM current control is used to form an APF. A simple P-I (proportional-integral) dc bus voltage controller with reduced energy storage capacitor is employed in the APF. A set of lagging/leading power-factor linear loads and a diode rectifier fed capacitive load and ac voltage regulator fed inductive load as the non-linear loads are taken on ac mains to demonstrate the Effectiveness of the proposed APF for reactive power and harmonic compensation. A detailed steady state and dynamic performance of The APF is presented and discussed briefly.

Limitations of Passive Filters:

Fixed Compensation

- Passive filters are designed for specific frequencies and load conditions.
- They cannot adapt dynamically to changing load profiles or harmonic levels.

Resonance Issues

- Can create series or parallel resonance with the power system, leading to amplification of harmonics instead of suppression.
- This may damage equipment or cause voltage instability.

Overloading and Detuning

- Components (especially capacitors and inductors) can become overloaded due to harmonic currents.
- Aging or frequency shifts may cause detuning, reducing the filter's effectiveness.

Large Size and Weight

- To target lower-order harmonics effectively, passive filters require large inductors and capacitors, making them bulky.

Limited Filtering Range

- They target only specific harmonic orders (e.g., 5th or 7th).
- Not effective for higher-order or non-characteristic harmonics.

Reactive Power Variation

- Provide **constant reactive power**, which may not match the system's varying needs.
- Can lead to **leading power factor** (overcompensation), especially under light loads.

System Description:

The Figure shows the fundamental building block of the proposed parallel APF. It is comprised of a standard single-phase voltage source MOSFET-based bridge inverter with a DC bus capacitor and a DC boost voltage for an effective current control. A **hysteresis rule-based carrier less PWM current control technique** is used to provide a fast dynamic response of the APF.

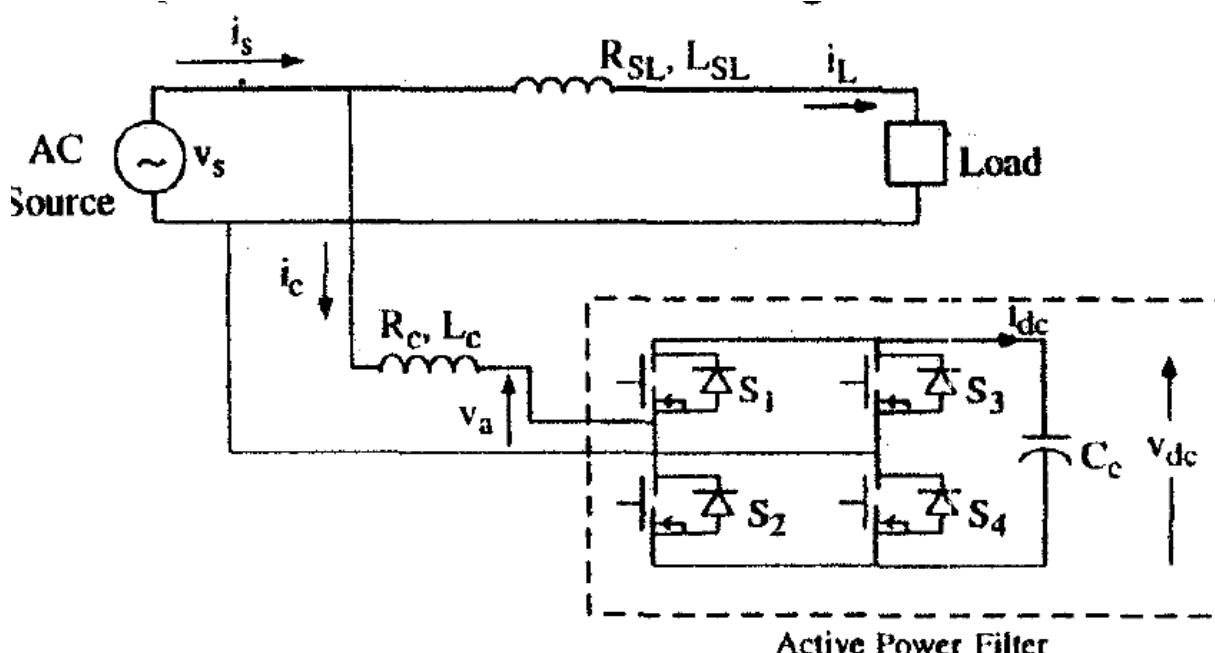


Figure 1 Basic circuit of the power circuit

Control Scheme:

Figure shows the block diagram of an overall control scheme for the APF system. DC bus voltage and supply voltage and current are sensed to control the APF. AC source supplies fundamental active power component of load current and fundamental component of a current to maintain average dc bus voltage to a constant value. The later component of source current is to supply losses in VSI such as switching loss, capacitor leakage current etc. in steady state and to recover stored energy on the dc bus capacitor during dynamic conditions such as addition or removal of the loads. 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 by 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 carrierless PWM current controller to derive 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 and reactive components of the load current.

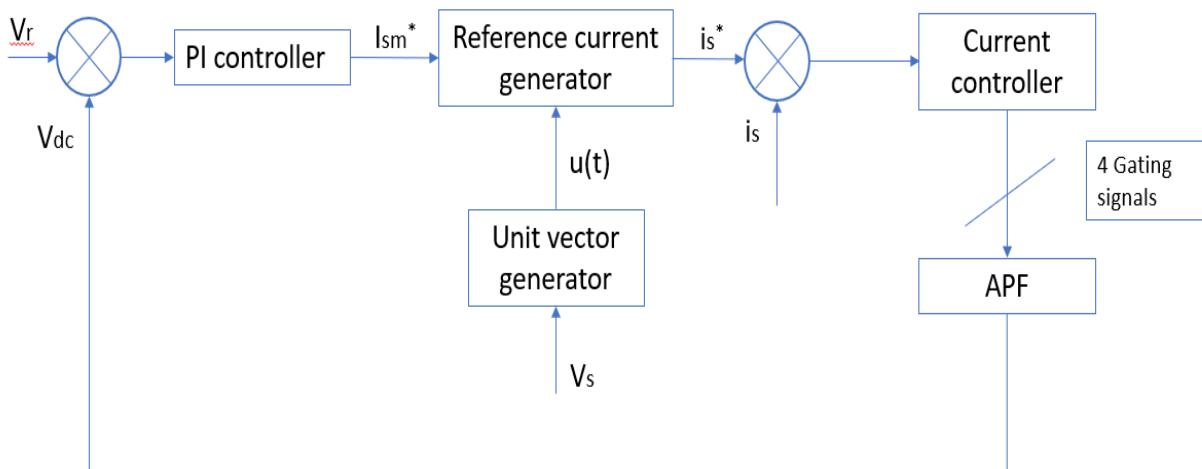


Figure 2 Basic circuit of the controller

Analysis and Model Equations:

A) Voltage Controller: A P-I (proportional-integral) controller is used to regulate the de bus capacitor voltage of the APF. The dc bus capacitor voltage V_{dc} is sensed using a voltage sensor and compared with set reference voltage (V_r). The resulting voltage error ($V_e(n)$) at nth sample instant is expressed as:

$$V_e(n) = V_r(n) - V_{dc}(n)$$
$$V_o(n) = V_o(n-1) + K_p\{V_e(n) - V_e(n-1)\} + K_i V_e(n)$$

where

V_{dc} = DC bus capacitor voltage

V_r = Set reference voltage

$V_e(n)$ = Voltage error at nth sample instant

$V_o(n)$ = Output of PI voltage controller

This output $V_o(n)$ of the voltage controller is limited to safe permissible % and resulting limited output taken as peak value of supply current I_{sm}^* .

B) Reference Current Generation: From sensed supply voltage ($V_{sm} \sin \omega t$), a unit vector template is estimated by computing its peak value (V_{sm}), The unit vector is as:

$$u(t) = v_s/V_{sm} = \sin \omega t$$
$$i_s^*(t) = I_{sm}^* u(t) = I_{sm}^* \sin \omega t$$

where

V_{sm} = Peak value of supply voltage

$I_{sm}^*(t)$ = Peak estimated value of supply current

i_s^* = Reference source current

C) Current Controller: The carrierless PWM hysteresis current controller contributes to switching pattern of the APF devices.

$$v_a = V_{dc}(S_A - S_B)$$

where

SA = 1 ; S1 ON
SA = 0 ; S2 ON
SB = 1 ; S3 ON
SB = 0 ; S4 ON

D) Active power filter

AC side -

$$R_C i_C + L_C \frac{d}{dt} i_C + v_A = v_S$$

$$\frac{d}{dt} i_C = \{v_S - v_A - R_C i_C\}/L_C$$

DC side -

$$\frac{d}{dt} v_{DC} = i_{DC} / i_C$$

$$i_{DC} = i_C (S_A - S_B)$$

where

V_A = APF voltage

R_C and L_C = APF resistor and inductance

E) Rectifier with capacitive loading

$$R_{SL} i_L + L_{SL} di_L/dt + v_L = v_S$$

$$P i_L = (v_S - v_L - R_{SL} i_L)/L_{SL}$$

$$dv_L/dt = (i_d - i_R)/C_L$$

where- R_{SL} and L_{SL} = Source impedance elements

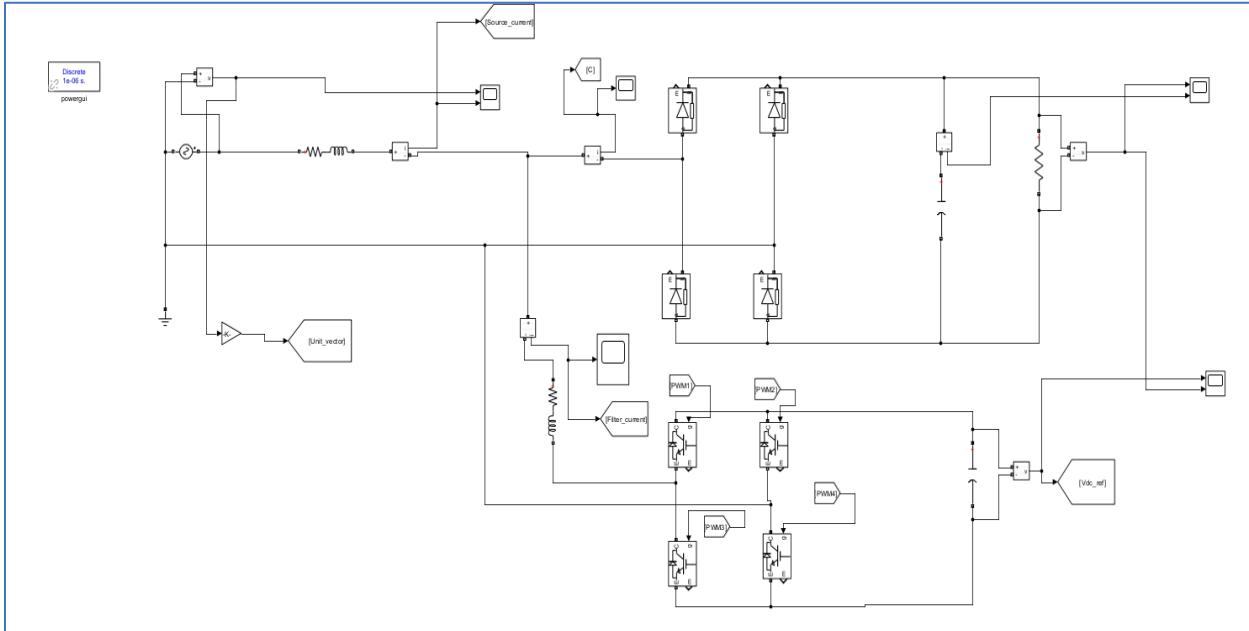
i_d = Magnitude of i_L

i_R = Resistive DC load current

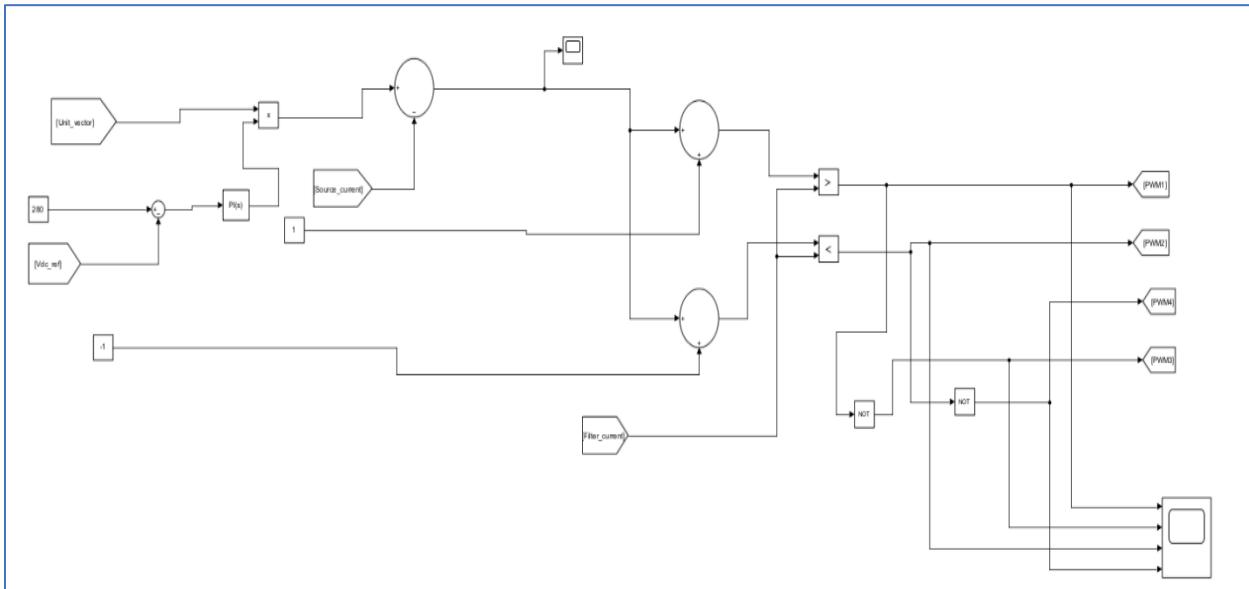
C_L = Load capacitor

v_L = voltage across load capacitor C_L

Circuit diagram with Active power filter



Control Architecture



Waveforms

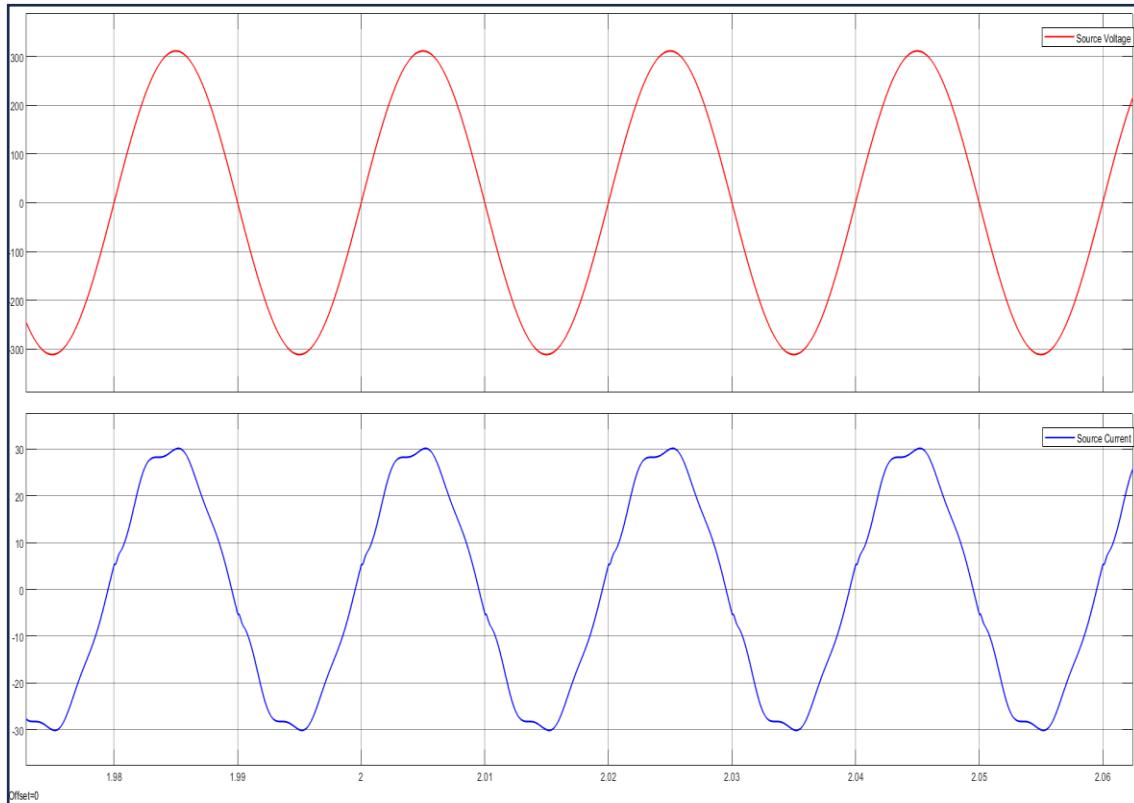


Figure 3 Source current

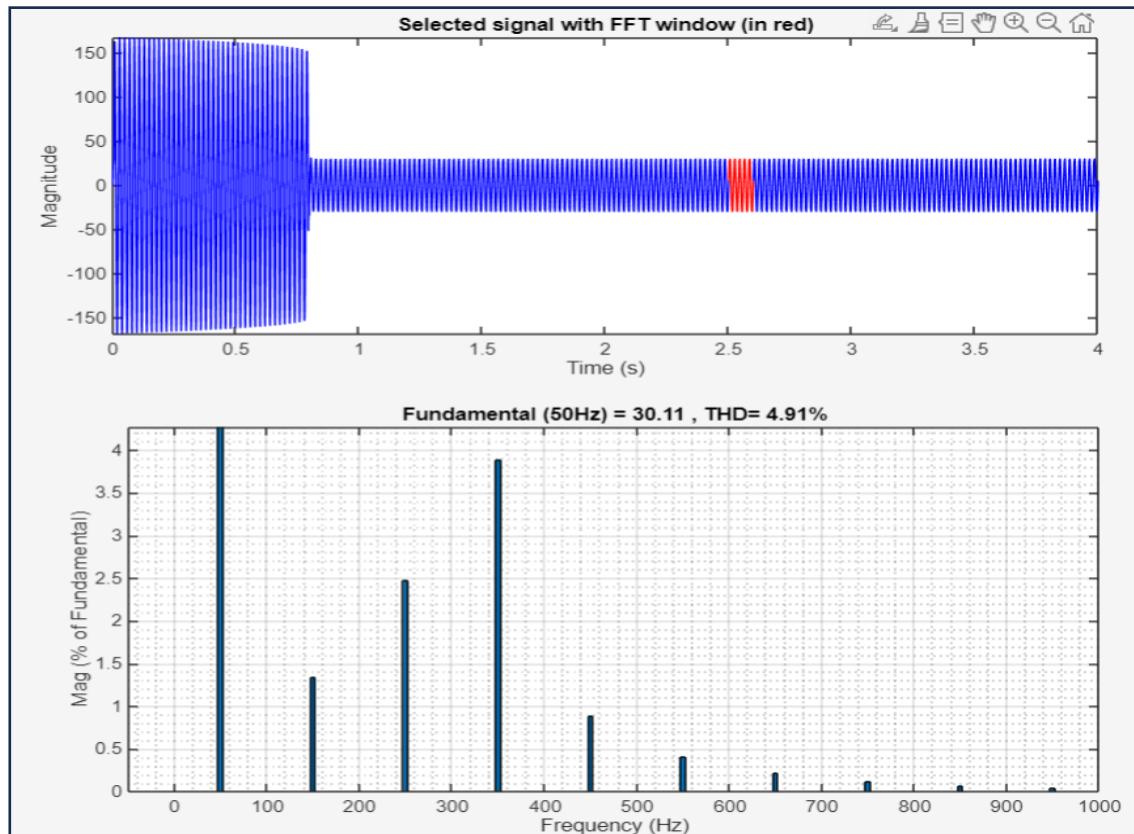


Figure 4 Source current THD

Prof. D Venkatramanan
EN662 Mini-project report

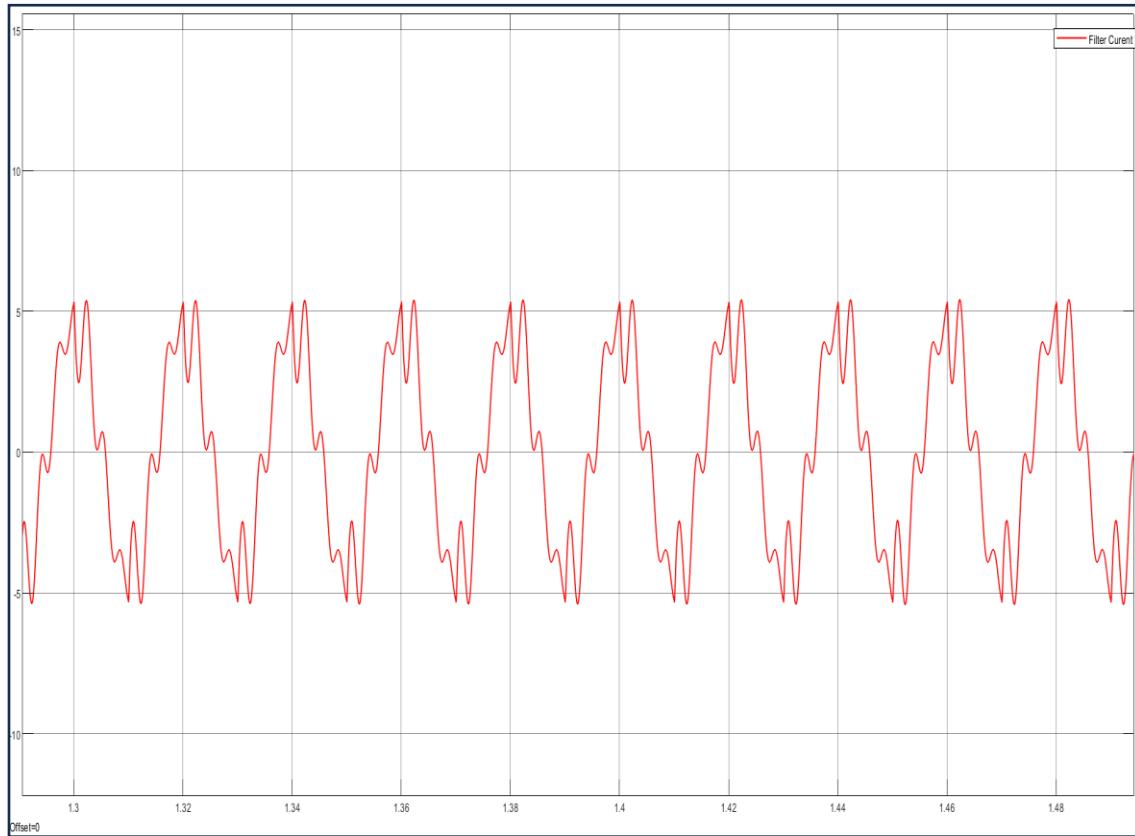


Figure 5 Filter current

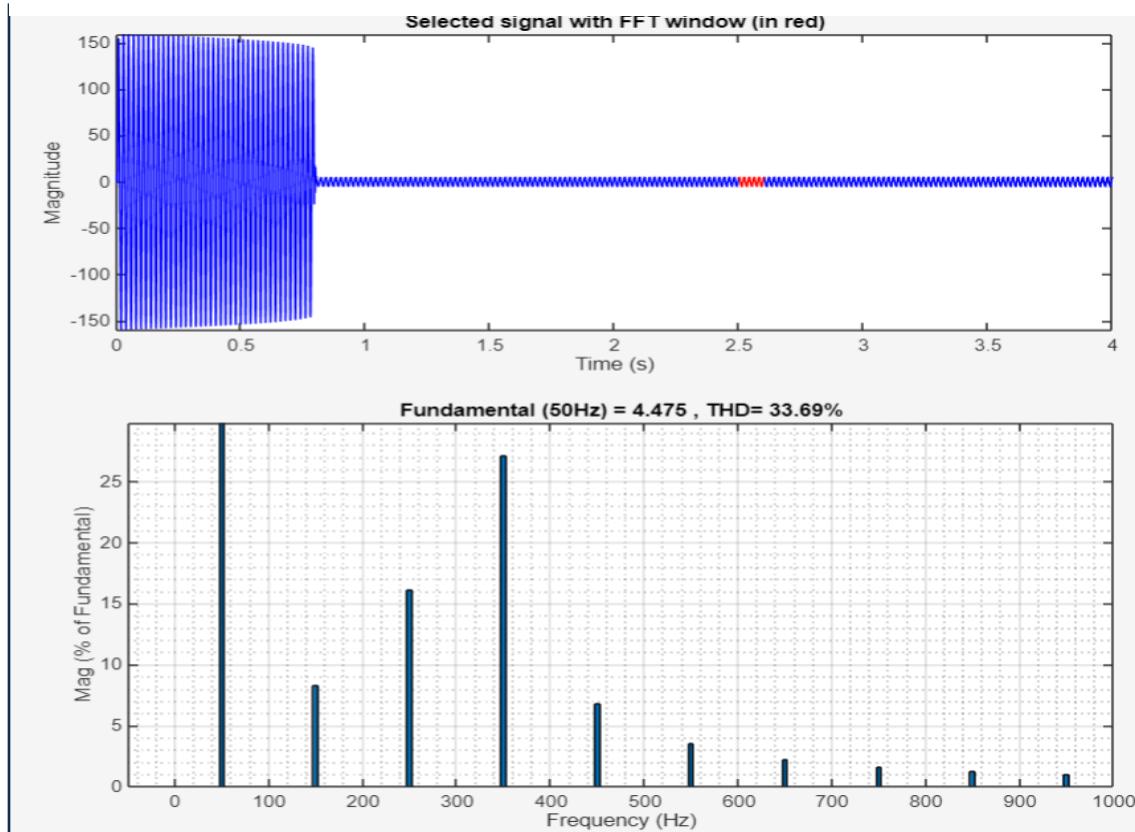


Figure 6 Filter current THD

Design details

- Supply : V_s (rms) = 220 V, f = 50 Hz,
- Filter data : R_c = 0 ohm,
 L_c = 4 mH,
 C_c = 50 microF,
- Series impedance : R_{SL} = 0.5 ohm,
 L_{SL} = 1 mH,
- Controller data : K_p = 0.45, K_i = 1
- Load : R_L = 10 C_L = 10 microF

Conclusion

A simple P-I controller based APF has been found effective to provide reactive power and harmonic compensation for the variety of loads. An excellent performance of APF system has been observed as a power-factor controller and an ideal reactive power compensator. APF is able to reduce the harmonics well below 5 % in all the cases of extremely reactive and harmonic polluted loads. APF has maintained sinusoidal supply current in phase with the supply voltage resulting in unity power-factor of the supply both in steady state and transient conditions. It is concluded that the proper selection of value of dc bus capacitor and PI controller parameters results in satisfactory performance of the APF system. Experimental verification of the proposed APF is being performed and verified. It can further be extended for Grid connected PV systems also. (Already been implemented)