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Power Quality Control using Hybrid Active Power filters

A Surya Prakash & M Lakshminarayan
Assistant Professor, Dept of EEE, SRTIST-Nalgonda, T.S, INDIA

Civilian Military Engineer Services-Defense

Abstract- *These power quality problems reduce the life time and efficiency of the equipment. Thus, to enhance the performance of the consumer equipment and also the overall performance of the system these problems should be mitigated. The main affect caused by these problems is the presence of harmonics. This leads to the overheating of the equipment, insulation failure and over speeding of induction motors etc. The solution to overcome these problems is to filter out these harmonics. For this purpose there are many filters topologies present in the literature. In this project a hybrid filter which is a combination of shunt active filter and shunt passive filter is studied. This project presents the control strategy to control the filter in such a way that the harmonics are reduced. The proposed control strategy is simulated in MATLAB SIMULINK and the results are presented.*

I. INTRODUCTION

Electrical energy is the most efficient and popular form of energy and the modern society is heavily dependent on the electric supply. 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 [1-4]. The quality of power delivered to the consumers depends on the voltage and frequency ranges of the power. If there is any deviation in the voltage and frequency of the electric power delivered from that of the standard values then the quality of power delivered is affected. Now-a-days with the advancement in technology there is a drastic improvement in the semi-conductor devices. With this development and advantages, the semi-conductor devices got a permanent place in the power sector helping to ease the control of overall system. Moreover, most of the loads are also semi-conductor 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 [5-7]. This power conversion contains lot of switching operations which may introduce discontinuity in the current. Due to this discontinuity and non-linearity, harmonics are present which affect the quality of power delivered to the end user. In order to maintain the quality of power delivered, the harmonics should be filtered out. Thus, a device named Filter is used which serves this purpose.

There are many filter topologies in the literature like- active, passive and hybrid. In this project the use of hybrid power filters for the improvement of electric power quality is studied and analyzed.

THESIS OBJECTIVES:

The main objective of this project is to control the hybrid power filter such that the harmonics in the current waveform are reduced. The control algorithm has the following objectives-

To control the voltage injected by APF such that it compensates the reactive power and load current harmonics

To improve the passive filter performance

To make the whole compensating equipment to act as linear, balanced, resistive load on the system

II. Hybrid Power Filters

The active power filters are better solution for power quality improvement but they require high converter ratings. So to overcome the above drawback, hybrid power filters are designed. The hybrid power filters are the combination of both active and passive power filters. They have the advantage of both active and passive filters [8, 9]. 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 merits and demerits.

A. Shunt APF and Series APF:

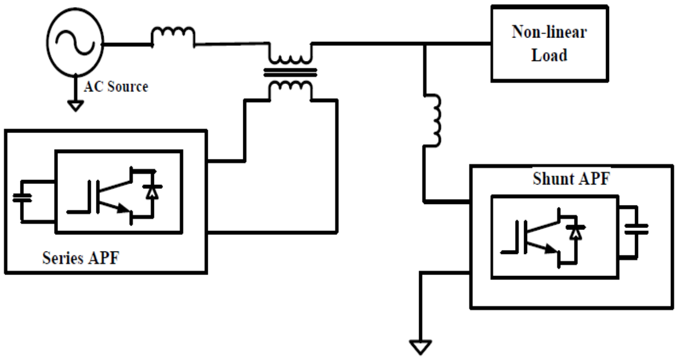


Figure 1: Shunt APF and Series APF Combination

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. 1. This combination finds its application in Flexible AC Transmission Systems (FACTS). But the control of APF is complex and this combination involves two APF and hence the control of this filters configuration is even more complex. Thus, this filter combination is not used widely.

B. 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. 2.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.

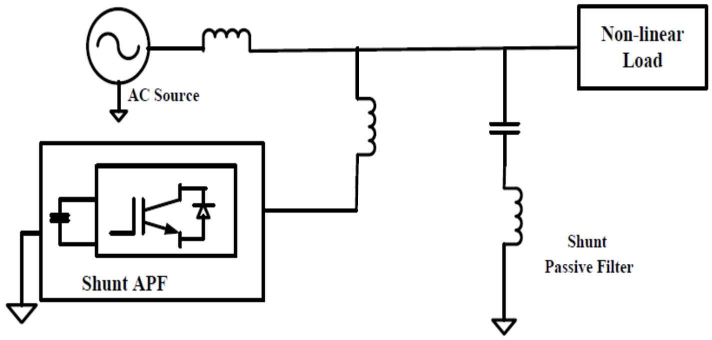


Figure 2: Shunt APF and Shunt Passive Filter Combination

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.

C. 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 [10]. 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.

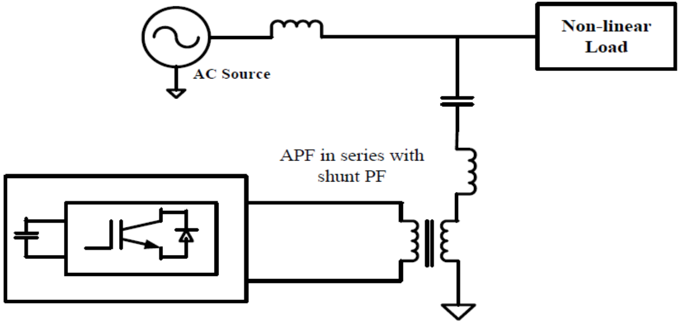


Figure 3: APF in series with Shunt Connected Passive Filter

D. Series APF with Shunt Connected Passive Filter:

The Series APF and Shunt APF combination seen in Fig. 1 has the problem of complex control strategy. To overcome this drawback, the shunt APF is replaced by a shunt connected passive filter [11]. 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.

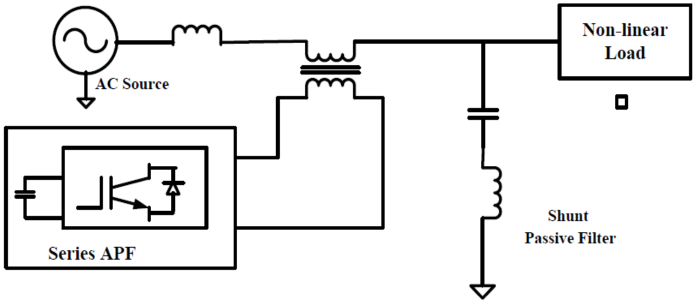


Figure 4 Series APF with Shunt Connected Passive Filter

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 [12].

This section deals with different filter topologies that are used for the improvement of electric power quality. It explains in detail each filter configuration along with their merits and demerits. From the above discussion, it is clear that the passive filters are low cost solution but are not effective. The active power filters can overcome the drawbacks of passive filter but their control is complex and difficult to implement. Thus, a hybrid filter is chosen which works effectively to the quality of power. Among the different available hybrid filter configurations, the shunt APF with a shunt connected passive filter best serves the purpose.

III. Proposed Control Scheme of HAPF

The control scheme mainly comprises three parts which are-a Fuzzy controller, a three phase sine wave generator and the generation of switching signals.

The peak value or the reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a predefined reference value. The error signal is then processed in a Fuzzy controller, which contributes to zero steady state error in tracking the reference current signal. The output or the PI controller is considered as peak value of the supply current (Imax), which is composed of two components. One is the fundamental active power component of load current and other is the loss component of the active power filter, to maintain average capacitor voltage to a constant value (i.e. Imax= Ism+ IsL).

Peak value of the current (Imax) so obtained is multiplied by the unit sine vectors in phase with the source voltages to obtain the reference compensating currents. Three phase reference current templates can be detected by using only one voltage sensor followed by a sine wave generator for generating a sinusoidal signal of unity amplitude, and in phase of mains voltages. It is multiplied by the output of the Fuzzy controller to obtain the reference current of phase‗A‘ . The other two phase reference currents can be obtained by a 120 phase shifter. In this way the desired reference currents can be obtained which is balanced and sinusoidal, irrespective of the distorted mains.

These estimated reference currents and the sensed actual source currents are given to a hysteresis controller to generate the switching signals for the inverter. The difference of the reference current template and the actual current decides the operation or the switches. To increase the current of a particular phase the lower switch of the inverter if that particular phase is turned on while to decrease the current the upper switch of the respective phase is turned on. A lockout delay can be given between the switching of the upper and the lower device to avoid the shoot through problem. These switching signals after proper isolation and amplification should be given to the switching devices. Due to these switching actions a current flows through the inductor to compensate the harmonic current and reactive power of the load so that only active power is drawn from the source

Design of DC Link Capacitor

In this scheme the role of the DC link capacitor is to absorb/supply real power demand of the load during transient. Hence the design of the DC link capacitor is based on the principle of instantaneous power flow. Equalizing the instantaneous power flow on the DC and AC side of the inverter considering only fundamental component

$$V_{dc}\, I_{dc} = v_{ca}(t)\, i_{ca}(t) + v_{cb}(t)\, i_{cb}(t) + v_{cc}(t)\, i_{cc}(t)$$

Assuming that three phase quantities are displaced by 120 degree with respect to each other, ϕis the phase angle by which the phase current lags the inverter phase voltage, and sqrt(2) Vc and sqrt(2)Ic are the amplitudes of the phase voltage and current, respectively of the input side of the inverter

$$V_{dc}\, I_{dc} = 2V_{ca}\, I_{ca} \sin \omega_1 t \sin (\omega_1 t - \phi_a) + 2V_{cb}\, I_{cb} \sin (\omega_1 t - 120^0) \sin (\omega_1 t - 120^0 - \phi_b) + 2V_{cc}\, I_{cc} \sin (\omega_1 t + 120^0) \sin (\omega_1 t + 120^0 - \phi_c)$$

Case I:If the three phase system is balanced-

Then,

$$V_{ca} = V_{cb} = V_{cc} = V_c,$$

$$I_{ca} = I_{cb} = I_{cc} = I_c, \text{ and}$$

$$\phi_a = \phi_b = \phi_c = \phi$$

Hence,

$$V_{dc}\, I_{dc} = 3\, V_c\, I_c \cos \phi$$

i.e. the DC side capacitor voltage is a DC quantity and ripple free. However, it consists of high frequency switching components, which have a negligible effect on the capacitor voltage.

Case II: If the three phase system is unbalanced

$$V_{dc}\, I_{dc} = (V_{ca}\, I_{ca} \cos \phi_a + V_{cb}\, I_{cb} \cos \phi_b + V_{cc}\, I_{cc} \cos \phi_c) - [V_{ca}\, I_{ca} \cos \quad (2\omega_1 t\, \phi_{a)} + V_{cb} I_{cb} \cos (2\omega_1 t - 240^0 - \phi_{b)} + V_{cc} I_{cc} \cos (2\omega_1 t + 240^0 - \phi_c)]$$

The above equation shows that the first term is a dc component, which is responsible for the power transfer from dc side to the AC side. Here it is responsible for the loss component of the inverter and to maintain the DC side capacitor voltage constant. Hence the proposed active power filter supplies this loss component. The second term contains a sinusoidal component at twice the fundamental frequency (second harmonic power) that the active power filter has to compensate. This ac term will cause the second harmonic voltage ripple superimposed on the DC side capacitor voltage.

The peak to peak ripple voltage is given by –

$$V_{pp} = \pi * I_{pp} * X_c$$

Where, Ipp is the peak to peak second harmonic ripple of the DC side current.

The maximum value of the Vpp can be obtained as –

$$V_{pp} = (\pi * I_{c1,\, rated}) / (\sqrt{3}\, \omega * C_f)$$

Case III: Since the total load power is sum of the source power and compensator power (i.e. PL= Pc+ Ps), so that when load change takes place, the changed load power must be absorbed by the active power filter and the utility.

$$\Delta P_L = \Delta P_c + \Delta P_s$$

Due to the term ΔPc there will be fluctuations in the DC link voltage. The magnitude of this voltage fluctuation depends on the closed loop response, and can be made smaller by a suitable design of controller parameters.

Hence selection of capacitor value Cf can be governed by reducing the voltage ripple. As per the specification of Vpp, max and Ic1, rated the value of the capacitor can be found from the following equation–

$$C_f = (\pi * I_{c1,\, rated}) / (\sqrt{3}\, \omega * V_{pp,\, max})$$

It is observed that the value of Cf depends on the maximum possible variation in load and not on the steady state value of the load current. Hence, proper forecasting in the load variation reduces the value of Cf.

Selection of Reference Capacitor Voltage

The reference value of the capacitor voltage Vdc,ref is selected mainly on the basis of reactive power compensation capability. For satisfactory operation the magnitude of Vdc,ref should be higher than the magnitude of the source voltage Vs. By suitable operation of switches a voltage Vc having fundamental component Vc1is generated at the ac side of the inverter. This results in flow of fundamental component of source currentIs1, as shown in fig 5. The phasor diagram for Vc1>Vs representing the reactive power flow is also shown in this figure. In thisIs1representfundamental component

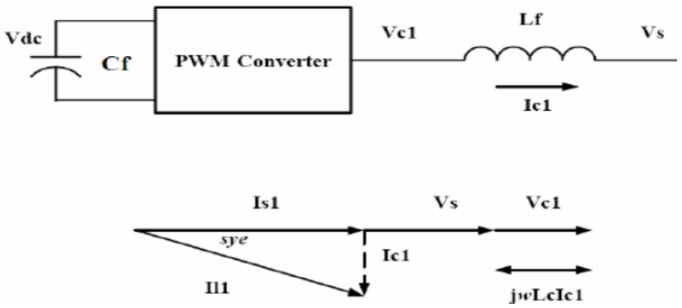


Fig 5: Single line and vector diagrams for shunt APF

Let us consider that the load is drawing a current IL1, which lags the source voltage by an angle ϕand the utility voltage is sinusoidal and given by

Vs= Vm sinωt

As per the compensation principle active power filter adjusts the current Ic1to compensate the reactive power of the load. In order to maintain Is1in phase with Vs, active filter should compensate all the fundamental reactive power of the load. The vector diagram represents the reactive power flow in which Is1is in phase with Vs and Ic1is orthogonal to it.

Form the vector diagram

$$V_{c1} = V_s + j\omega\ L_f I_{c1}$$

i.e. to know Vc1 it is necessary to know Ic1

$$I_{c1} = \frac{V_{c1} - V_s}{\omega L_f}$$

$$= \frac{V_{c1}}{\omega L_f}\left(1 - \frac{V_s}{V_{c1}}\right)$$

Now the three phase reactive power delivered from the active power filter can be calculated from the vector diagram as

$$Q_{c1} = Q_{L1} = 3\ V_s\ I_{c1}$$

$$= 3\ Vs\ \frac{V_{c1}}{\omega L_f}\left(1 - \frac{V_s}{V_{c1}}\right)$$

From these equations

If Vc1 >Vs, Qc1 is positive, and

If Vc1 <Vs, Qc1 is negative.

i.e. active power filter can compensate the lagging reactive power from utility only when Vc1 > Vs. For Vc1 <Vs, it will draw reactive power from the utility. The upper limit of Vc1 is calculated on the basis of maximum capacity of the active power filter determined as-

Maximum capacity of the active filter can be obtained by equating

$$\frac{dQ_{c1}}{dV_s} = 0$$

$$\frac{d}{dV_s}\left(\frac{3V_sV_{c1}}{\omega L_f} - \frac{3V_s^2}{\omega L_f}\right) = 0$$

i.e. the active power filter can supply maximum reactive power when Vc1 = 2Vs. The maximum capacity can be obtained by putting Vc1 = 2Vs

$$Q_{c1,\max} = \frac{3V_s^2}{\omega L_f}$$

Hence, the Vc1 (and Vdc) must be set according to the capacity requirement of the system. From above discussion the range of the Vc1 can be given as –

Vs< Vc1 2Vs

Larger Vc1 means higher Vdc and thus higher voltage stress on the switches.

If the inverter is assumed to operate in the linear modulation mode i.e. modulation index varies between 0 and 1, then the amplitude modulation index is given by-

$$m_a = \frac{2\sqrt{2}V_{c1}}{V_{dc}}$$

And the value of Vdc is taken as

$$V_{dc} = 2\sqrt{2}\ \ V_{c1}$$

Design of PI controller

The controller used is the Fuzzy controller that takes in the reference voltage and the actual voltage and gives the maximum value of the reference current depending on the error in the reference and the actual values. The mathematical equations for the Fuzzy controller are:

The voltage error V(n) is given as:

V (n) =V(n)* -V (n)

The output of the Fuzzy controller at the nth instant is given as:

I(n)=I(n-1)+ ΔKp [V(n)-V(n-1)]+ ΔKi [V(n)-V(n-1)]

The real/reactive power injection may result in the ripples in the DC link voltage. The magnitude of these voltage ripples is insignificant for the compensation of linear load, but it is significant for compensation of non-linear loads. When the DC link voltage is sensed and compared with the reference capacitor voltage, to estimate the reference current, the compensated source current will also have sixth harmonic distortion for three-phase system and second harmonic distortion for single-phase system. A low pass filter is generally used to filter these ripples which introduce a finite delay and affect the transient response. To avoid the use of this low pass filter the capacitor voltage is sampled at the zero crossing of the source voltages.

Design of Passive Shunt Filter

The passive shunt filter consists of first order series tuned low pass filters for 5th and 7th order harmonics. For the series tuned low pass filters, the impedance is given by:

$$Z_{sh(h)} = \left[R + j\left(hX_L - \frac{X_C}{h} \right) \right]$$

$$X_L = \frac{X_C}{h_n^2}$$

$$X_c = \left(\frac{h_n^2 - 1}{h_n^2} \right) \frac{V^2}{Q_{sh}}$$

Where Qsh is the reactive power provided by the passive filter, h is the harmonic order of the passive filter; XL is the reactance of inductor. Xc is the reactance of the capacitor at fundamental frequency. The reactive power requirement may be initially assumed around 25% of the rating of the load. It may be equally divided among different filter branches. The values of series tuned elements may be calculated from eqn. (2.5). The quality factor for low pass filter (defined as QF =XL/R), is consider as 30 in this work to calculate the value of the resistive element.
The resonant frequency for the hth harmonic is given as:

$$f_h = \frac{1}{(2\pi hCR)}$$

Quality factor can be defined as

$$Q = \frac{L}{(CR^2)}$$

The values of filter components can be calculated from above equations.
The design of the passive shunt filter is carried out as per the reactive power requirements. This filter is designed to compensate the requirements of reactive power of the system. Therefore, this passive filter helps in maintaining the dc link voltage regulation within limits along with the power factor improvement. It also sinks the harmonic currents of frequencies at which the passive filters have been tuned.

IV. SIMULATION RESULTS

The proposed control strategy is simulated in MATLAB SIMULINK environment to check the performance of the control strategy in improving the system behavior. The simulation is carried under following load condition-

- Non-linear Unbalanced Load

The performance of the system with the proposed control strategy under different load conditions is discussed in detail in the following section.
The power system may experience unbalanced load conditions at many times. Thus, the behavior of the proposed control strategy is analyzed by simulating it under unbalanced loading conditions. Here the unbalanced load is created by connecting two three-phase uncontrolled rectifiers with inductor and resistor in series on the DC side.

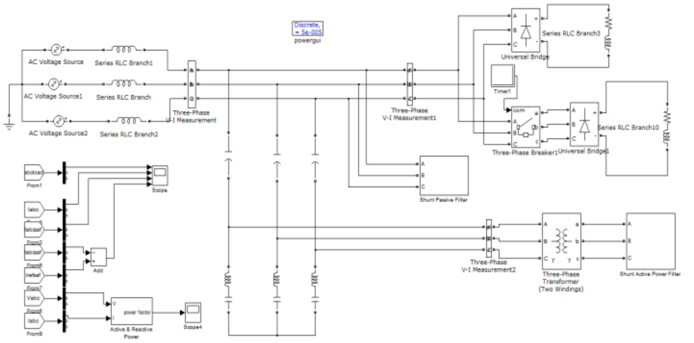


Figure 6: Simulation circuit of proposed Hybrid Active Power Filter

The simulation analysis was conducted with Shunt Passive filter of parallel LC filters, the parameters are taken as follows
L1= 1.77mH, C1= 49.75 µF
L2= 1.37 mH, C2= 44.76 µF
The test system is studied with constant and variable non-linear loads at receiving side of network. A constant non-linear load with DC side load as given below:
R1= 20 ohms, L1= 50 mH
Z1 = 20+ j(0.05) ohms
The total simulation analysis was carried out through 1 sec. A variable non-linear load also connected to load side with switching after 0.3 sec.
R2= 20 ohms, L2= 50 mH
Z2= 20+ j (0.05) ohms
Z1=Z2
The three phase load current waveform is shown in Fig. 6. Fig. 7(a) shows the load current waveform without any compensation. From the waveform it is clear that there many harmonics present in the system after 0.3 sec.

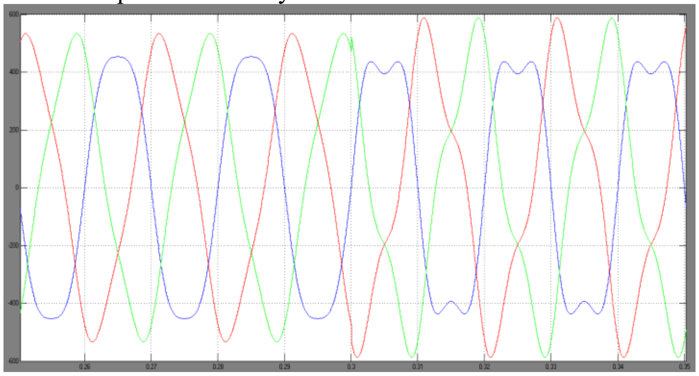


Figure 7 (a): Load current during power quality problem

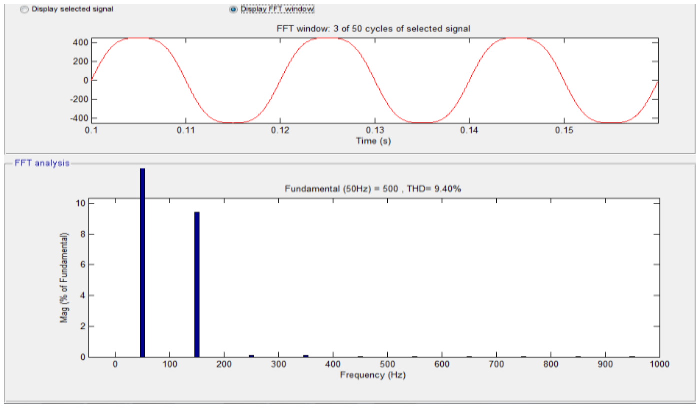


Figure 7(b): FFT analysis for load current before PQ problem (%THD = 9.40%)

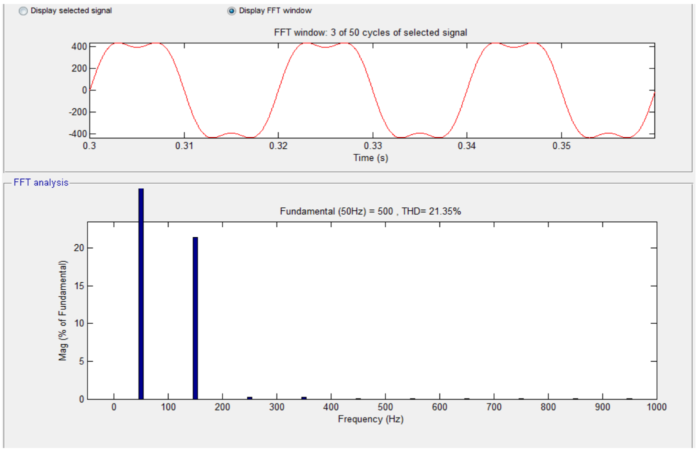


Figure 7(c): FFT analysis for load current after PQ problem (%THD = 21.35%)

Fig 8(a) shows the source current waveform with HAP filter. Thus, to reduce these harmonics, HAPF is connected and then the source current is changed as shown in Fig. 7(b). It is clear from the figure that the three phase source current is almost sinusoidal. Hence, the system performance is improved by connecting the APF even under unbalanced load conditions.

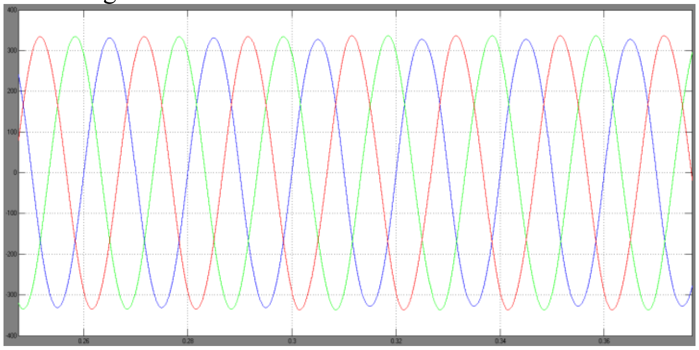


Fig 8 (a): Source current under non-linear load after 0.3 sec

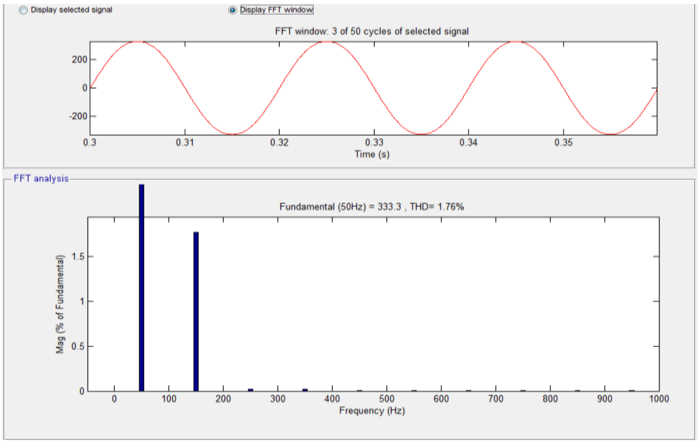


Fig 8(b): FFT analysis of Source current under non-linear load condition (THD= 1.76%)

Figure 9 shows the waveform of the Shunt active power filter current. It can clearly see that the amount of current injected by the Shunt active power filter is getting increasing after 0.3 sec means that SAPF acting with respect of time occurrence of PQ problem in the network.

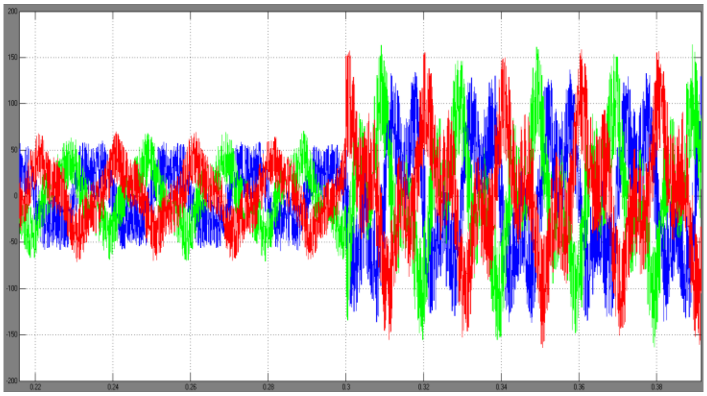


Figure 9: Shunt active power filter current

Figure 10 shows the difference between the reference SAP filter current and actual SAP filter current. It is observed that the error value is 3 amps before PQ problem occurrence. The error is getting increasing to 5 amps after 3 seconds due to non-linear load. By the Hybrid active power filter operation the error getting decreasing and became 1.45 amps after 0.5 seconds.

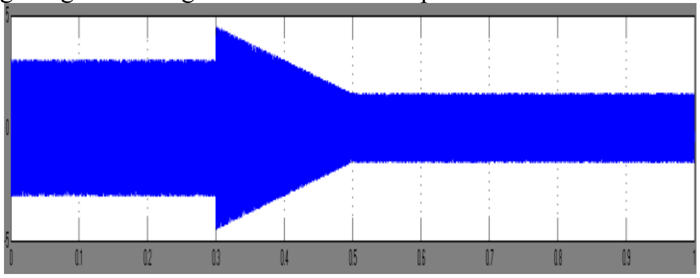


Fig 10: Difference between reference and actual SAPF current

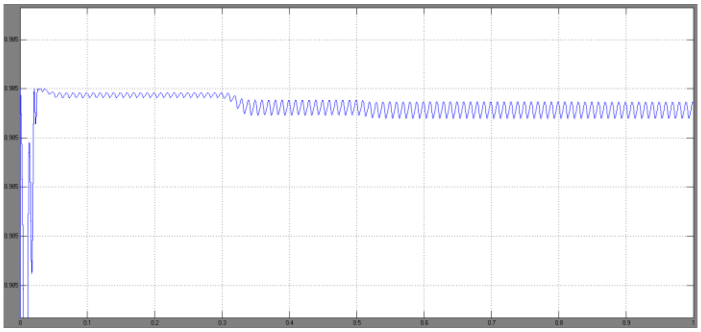


Fig 11: Power factor of the network (0.985)

This section presents the MATLAB SIMULINK results of the proposed control strategy at different operating conditions. The system is simulated with both balanced and unbalanced load. From the results it is inferred that the Active Power Filter is very helpful in improving the power quality of the system by filtering out the harmonics.

V. CONCLUSIONS

Thus, the reduction of harmonics and improving the power factor of the system is of utmost important. In this project a solution to improve the electric power quality by the use of Active Power Filter is discussed. From the study of Active Power Filter for power quality improvement the following conclusions are drawn-

- Most of the loads connected to the system are non-linear which the major sources of harmonics are in the system
- The non-linear load draws non-linear current from the supply
- Thus the voltage at PCC is also non-linear affecting the performance of end user equipment
- To compensate the load harmonics a filter is connected at the PCC which injects the compensating current
- To achieve this a Hybrid power filter with series connected APF 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 APF under different operating conditions
- The connection of APF improves the passive filter characteristics in addition to improve the system performance
- The APF works well even with variable loads and improves the power factor of the system
- The simulation is also carried out with unbalanced load and found that the APF 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 in electric power system.

FUTURE SCOPE:

The work done in this paper can be further extended such new improvements can be found. The feasible options are-

To simulate the proposed control strategy with grid faults and studies the behavior of APF in power quality improvement

To implement the control strategy using Artificial Intelligence (AI) techniques

REFERENCES

[1]. Awad, H.; Bollen, M. H J, "Power electronics for power quality improvements," *Industrial Electronics, 2003. ISIE '03. 2003 IEEE International Symposium on*, vol.2, no., pp.1129,1136 vol. 2, 9-11 June2003 doi: 10.1109/ISIE.2003.1267983

[2]. Singh, Bhim; Al-Haddad, K.; Chandra, A., "A review of active filters forpower quality improvement," *Industrial Electronics, IEEE Transactions on* ,vol.46, no.5, pp.960,971, Oct 1999 doi: 10.1109/41.793345

[3]. Rivas, D.; Moran, L.; Dixon, J.W.; Espinoza, J.R., "Improving passive filtercompensation performance with active techniques," *Industrial Electronics, IEEE Transactions on*, vol.50, no.1, pp.161, 170, Feb. 2003 doi:10.1109/TIE.2002.807658

[4]. Herrera, R.S.; Salmeron, P., "Instantaneous Reactive Power Theory: AComparative Evaluation of Different Formulations," *Power Delivery, IEEETransactions on* , vol.22, no.1, pp.595,604, Jan. 2007 doi:10.1109/TPWRD.2006.881468

[5]. Salmeron, P.; Litran, S.P., "Improvement of the Electric Power QualityUsing Series Active and Shunt Passive Filters," *Power Delivery, IEEE Transactions on*, vol.25, no.2, pp.1058,1067, April 2010 doi:10.1109/TPWRD.2009.2034902

[6]. M H J Bollen, *Understanding Po11 er Quality Problenis Voltage Sagsandlnterruptions,* New York, IEEE Press, 1999

[7]. Axente, N. G. Jayanti, M.Basu, and M. F. Conlon, “A 12 kVA DSP controlled laboratory prototype UPQC capable of mitigating unbalance in source voltage and load current,” IEEE Trans. Power Electron. ,vol. 25, no.6, pp. 1471–1479, Jun. 2010.

[8]. H. Akagi, “Active harmonic filters,” *Proc. IEEE*, vol. 93, no. 12, pp. 2128–2141, Dec. 2005.

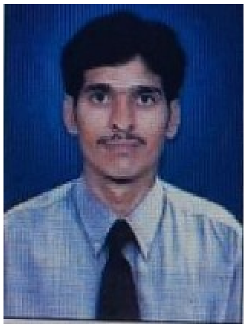
[9]. B. Singh, K. Al-Haddad, and A. Chandra, “A review of active filters forpower quality improvement,” *IEEE Trans. Ind. Electron.*, vol. 46, no. 5, pp.960–971, Oct. 1999.

[10]. J. W. Dixon, G. Venegas, and L. A. Moran, “A series active power filterbased on a sinusoidal current-controlled voltage-source inverter,”*IEEETrans. Ind. Electron.*, vol. 44, no. 5, pp. 612–620, Oct. 1997.

[11]. H. Yang and S. Ren, “A practical series-shunt hybrid active power filterbased on fundamental magnetic potential self-balance,” *IEEE Trans.PowerDel.*, vol. 23, no. 4, pp. 2089–2096, Oct. 2008.National Institute of Technology, Rourkela Page 48

[12]. A. Luo, Z. Shuai, W. Zhu, R. Fan, and C. Tu, “Development of hybrid activepower filter based on the adaptive fuzzy dividing frequency-control method,”*IEEE Trans Power Del.*, vol. 24, no. 1, pp. 424–432, Jan. 2009.

Author’s Profile



A Surya Prakash currently working Assistant professor at SRTIST-Nalgonda, under department of Electrical and Electronics Engineering.

M Lakshminarayan

Civilian
Military Engineer Services-Defense.