Performance Comparison of Hybrid Filter by Using Different Compensation Techniques

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Abstract: **Nonlinear loads (diode/thyristor rectifiers, SMPS, welding equipment, incandescent lighting) are degrading power quality in transmission and distribution grid systems.These non-linear loads result in harmonic or distortion current.Harmonic pollution in electrical networks causes voltage distortion, additional losses and heating in the electrical equipment, vibrations and noise in motors, malfunction and failures of sensitive equipments etc. When a voltage and/or current waveform is distorted, it causes abnormal operating conditions in a power system such as:Voltage Harmonics can cause additional heating in induction and synchronous motors and generators.Voltage Harmonics with high peak values can weaken insulation in cables, windings, and capacitors.Voltage Harmonics can cause malfunction of different electronic components and circuits that utilize the voltage waveform for synchronization or timing.Current Harmonics in motor windings can create Electromagnetic Interference (EMI).**

1. INTRODUCTION

A. Instantaneous Reactive Power Theory (pq Method)

This method is also known as *pq* method. Most APFs have been designed on the basis of instantaneous reactive power theory or *pq* method to calculate the desired compensation current. This theory was first proposed by Akagi and co-workers in 1984. The p-q theory is based on a set of instantaneous powers defined in the time domain. The three-phase supply voltages (*ua, ub, uc*) and currents (*ia, ib, ic*) are transformed using the Clarke (or α-β) transformation into a different coordinate system yielding instantaneous active and reactive power components. This transformation may be viewed as a projection of the three-phase quantities onto a stationary two-axis reference frame.
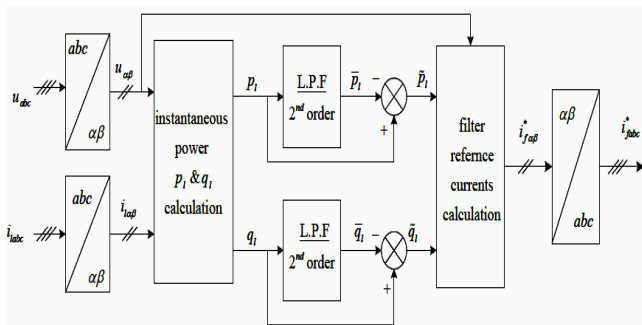
The Clarke transformation for the voltage variables is given by [7]:

$$\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{1}$$

Similarly, this transform can be applied on the distorted load currents to give:

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \\ i_{l0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \tag{2}$$

The instantaneous active power *p(t)* is given by:

$$p(t) = u_a i_{la} + u_b i_{lb} + u_c i_{lc} \tag{3}$$

This expression can be given in the stationary frame by:

$$p(t) = u_\alpha i_{l\alpha} + u_\beta i_{l\beta} \tag{4}$$

$$p_o(t) = u_0 i_{l0} \tag{5}$$

Where, *p(t)* is the instantaneous active power, *p0(t)* is the instantaneous homo-polar sequence power. Similarly the instantaneous reactive power can be given by:

$$q(t) = -\frac{1}{\sqrt{3}}[(u_a - u_b)i_{lc} + (u_b - u_c)i_{la} + (u_c - u_a)i_{lb}] \tag{6}$$

$$= u_\alpha i_{l\beta} - u_\beta i_{l\alpha} \tag{7}$$

In matrix form, the instantaneous active and reactive power can be given by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} \tag{8}$$

After separating the direct and alternating terms of instantaneous power, the harmonic components of the load currents can be given by using the inverse of equation (8) which gives:

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = \frac{1}{v_{s\alpha}^2+v_{s\beta}^2}\begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{s\alpha} \end{bmatrix}\begin{bmatrix} \widetilde{p_l} \\ \widetilde{q_l} \end{bmatrix} \qquad (9)$$

The APF reference current can be then given by:

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} \widetilde{i_{l\alpha}} \\ \widetilde{i_{l\beta}} \end{bmatrix} \qquad (10)$$

B. Synchronous Reference Theory (d-q Method)

In this method, called also the method of instantaneous currents *id, iq*, the load currents are transformed from three phase frame reference *abc* into synchronous reference in order to separate the harmonic contents from the fundamentals [6]. It gives better performance even in the case where the three phase voltage is not ideal.
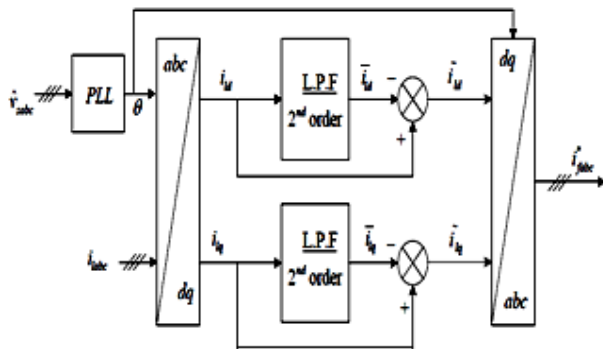
Transformation from three phase frame reference *abc* into synchronous reference is given by [8]:

$$\begin{bmatrix} i_{ld} \\ i_{lq} \\ i_{l0} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos\theta & \cos(\theta-\frac{2\pi}{3}) & \cos(\theta+\frac{2\pi}{3}) \\ -\sin\theta & -\sin(\theta-\frac{2\pi}{3}) & \sin(\theta+\frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}\begin{bmatrix} i_{la} \\ i_{lb} \\ i_{l0} \end{bmatrix}(11)$$

The currents in the synchronous reference can be decomposed into two parts as:

$$\begin{cases} i_{ld} = \overline{i_{ld}} + \widetilde{i_{ld}} \\ \\ i_{lq} = \overline{i_{lq}} + \widetilde{i_{lq}} \end{cases} \qquad (12)$$

The APF reference currents are given by:

$$\begin{bmatrix} i_{fd}^* \\ i_{fq}^* \end{bmatrix} = \begin{bmatrix} \widetilde{i_{ld}} \\ i_{lq} \end{bmatrix} \qquad (13)$$

In three phase system, APF currents can be calculated by the inverse Park transform which is defined as:

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos\theta & -\sin\theta \\ \cos(\theta-\frac{2\pi}{3}) & -\sin(\theta-\frac{2\pi}{3}) \\ \cos(\theta+\frac{2\pi}{3}) & \sin(\theta+\frac{2\pi}{3}) \end{bmatrix}\begin{bmatrix} i_{fd}^* \\ i_{fq}^* \end{bmatrix}$$

2. PASSIVE POWER FILTER TOPOLOGY

Passive filter is made only from passive elements.It does require an external power source(beyond the signal).Since most filters are linear, in most cases, passivefilters are composed of just the four basic linear elements – resistors, capacitors, inductors, and transformers.
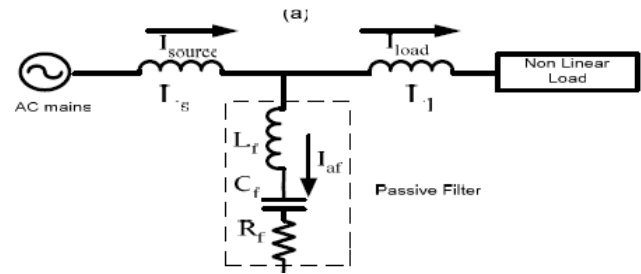
3. SHUNT ACTIVE POWER FILTER (SAPF) TOPOLOGY

Shunt active power filter has simple structure and construction, with a large dc link capacitor, and connected to the line by means of an inductor.For implementation of SAPF filter there are three main steps-
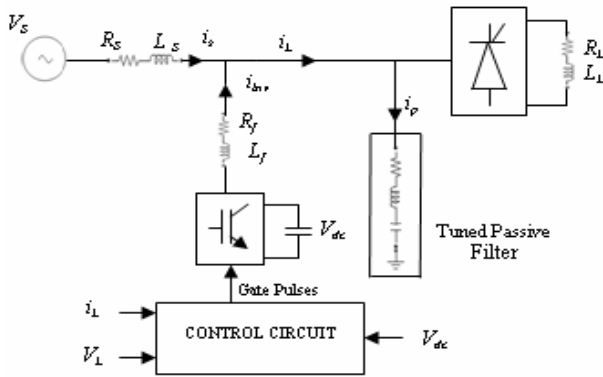*(a) Reference Current Generation*
(b) PLL (phase locked loop)
(c) Current tracking
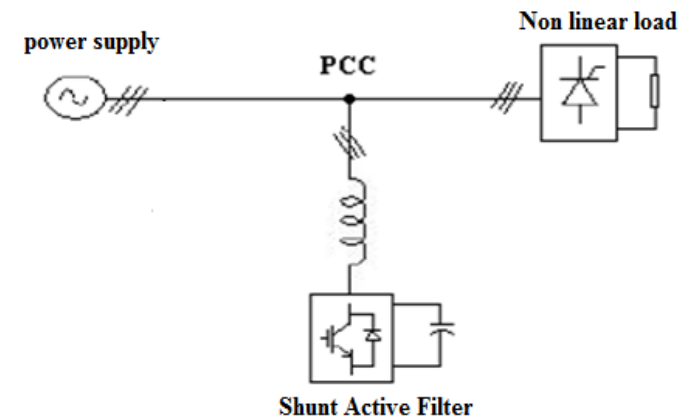
4. HYBRID SHUNT ACTIVE POWER FILTER TOPOLOGY

This is the combination of shunt active and passive filter topology

This gives more efficient result for harmonic compensation

5. SIMULATION RESULTS

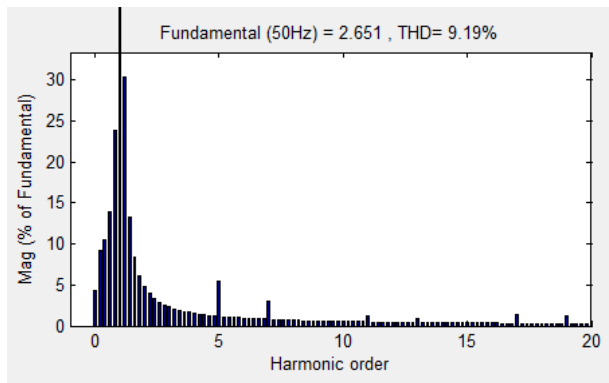Balanced Supply system & feeder is Stiff

Input voltage is 230 V

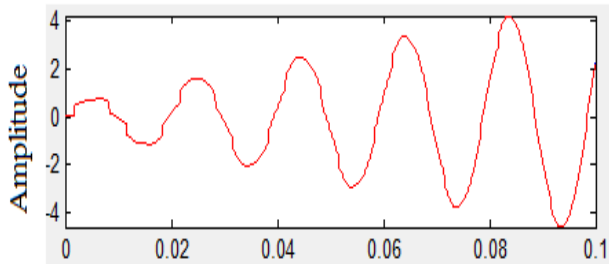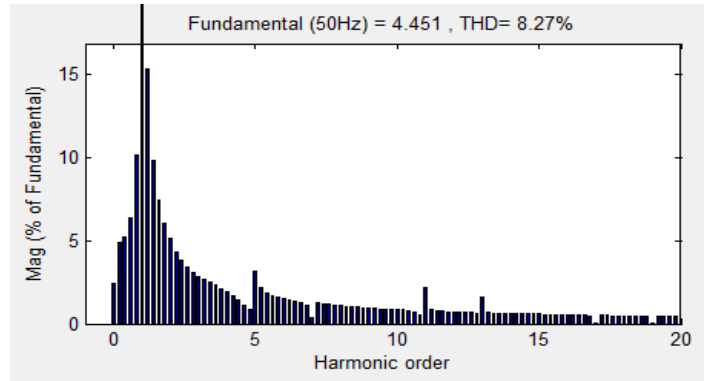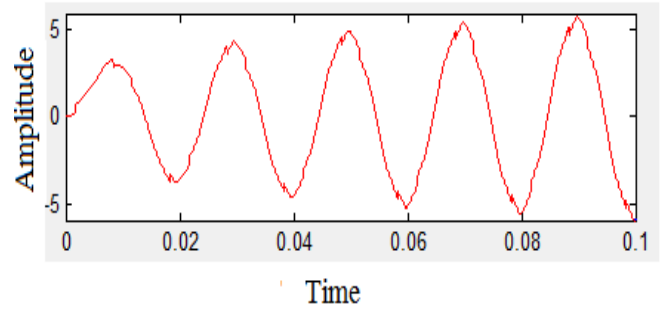Fig.2.Supply current and spectrum analysis after using APF

Fig.1.Supply current and spectrum analysis after using PPF
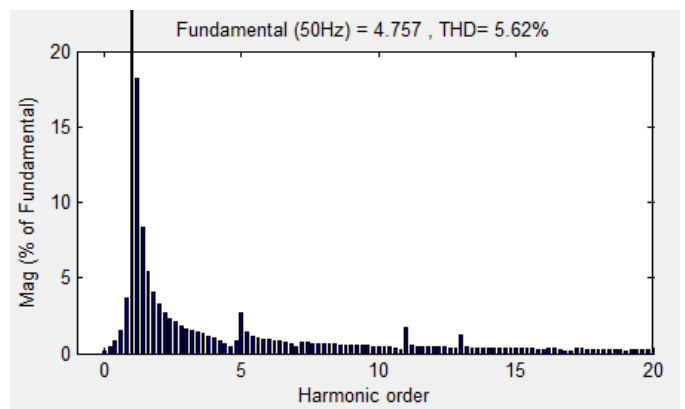

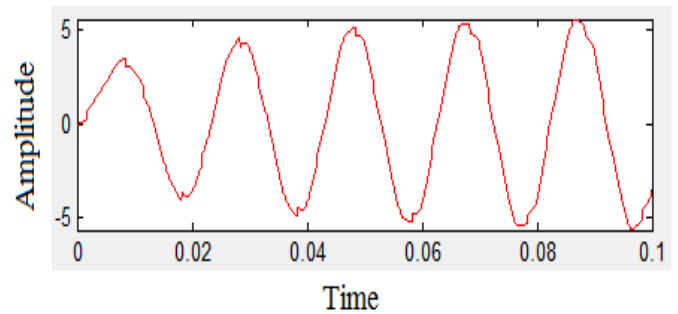Fig.2. Supply current and spectrum analysis after using APF and PPF

6. SIMULATION ANALYSIS

Table 1. Comparison of % of harmonics

Harmonic order	% of harmonics		
	Before Compensation	SAPF	SAPF + PPF
3rd	4.79	0.70	0.35
5th	18.91	3.28	0.96
7th	14.24	2.56	1.10
9th	1.16	0.89	0.74
11th	1.66	1.33	0.11
13th	7.75	1.34	0.45

7. SIMULATION ANALYSIS

Table 2. Comparison of % of THD

SYSTEM	% of THD
Before compensation	30.79
Passive Power Filter	9.19
Shunt Active Power Filter	8.27
Combination of Shunt Active power Filter and Passive power Filter	5.62

8. CONCLUSION

- The system of Passive power Filter, Shunt Active Power Filter and the combination of Passive power Filter and Shunt Active Power Filter is proposed in this work

- An inverter based hybrid shunt active power filter for medium voltage applications has been simulated

- Harmonics are detected through the SRF and the reference current has been generated and tracking is done using a current controller

- When compared to the three methods the combination of Passive power Filter and Shunt Active Power Filter is efficient for harmonic suppression and power factor improvement. By this method the % of THD can be reduced to 5.62.

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