Designing of Shunt Hybrid Power Filter to Mitigate Current Harmonics

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Abstract- The extreme utilization of Nonlinear Load (NL)causes power quality (PQ) problems in the distribution system such as current and voltage harmonics, sag, swell, flicker etc. The malfunctioning of the protective devices and de-rating of transformers is caused due to unbalanced currents in the system. This paper presented an improved design for Hybrid Power Filter, connected in parallel also known to be Shunt Hybrid Power Filter(SHPF).In SHPF shunt passive filter (PF) and Shunt Active Power Filter (SAPF) are combined together for mitigation of 5^{th} and 7^{th} order current harmonics. p-q theory is applied for controlling SAPF. The system is analyzed without filter, system with SAPF and SHPF in this paper. The simulation work was carried out using MATLAB/Simulink and results showed the efficient design characteristics of the SHPF over other designs simulated here.

Keywords- Power quality issues, harmonics, Active power filter, hybrid filter etc.

I. INTRODUCTION

Now a day's control of AC supply with power electronics devices has been increased in various applications tremendously. The harmonics drawn by non-linear characteristics of load results into reactive power flow from the AC system as well as injection of harmonic component of currents. This in conjunctionproduces unbalanced currents and excessive neutral current resulting in significant drop in efficiency of distribution system, reduced p.f., mal-functioning of protection equipments, de-rating of distribution system and connected apparatus, and so on. A harmonic current in the system is the main PQ problem [1]. Harmonics is nothing but the fluctuating component of the sine wave with the frequency integral times of the nominal frequency .Non linear load connected to the system produces this harmonics will pass through the AC supply up to the point of common coupling and will harmfully impinge on the other load connected to the system[2]- [3].

Earlier, PF were utilized for the harmonic mitigation because of their low cost and simplicity.This filter can be connected in series or parallel depending on the requirement. For shunt PF are preferred for current related PQ problems whereas series PF are used to compensate voltage related PQ problems. However they are applicable for particular harmonic exclusion. The main drawbacks are de-tuning,huge volume, resonance, system impedance dependent performance, etc [2]. To overcome all these drawbacks new technique in filters called as Active Power filters (APF) was developed. It injects the voltage and current with appropriate phase angle and magnitudes which mitigates the harmonics in the system produced due to NL. On the other hand in some applications their VA loading required is same as the load and as a result it turn into costly alternative for PQ problem mitigation. Other than this high power losses and high initial cost, this limits its broad application, mainly in huge rating system [3]-[10] Moreover, in many applications of NL both voltage- and current-based PQ problems are present and alone APF does not offer a complete solution to mitigate it. However, many research scholars have proposed several filter option for mitigation of PQ problems for different NLs. One of the most effective techniques called as Hybrid power filters (HPF) in which PF and APF are connected in the system have been introduced [11]-[16]. There are many possible connections of both filters as shown in the fig.1

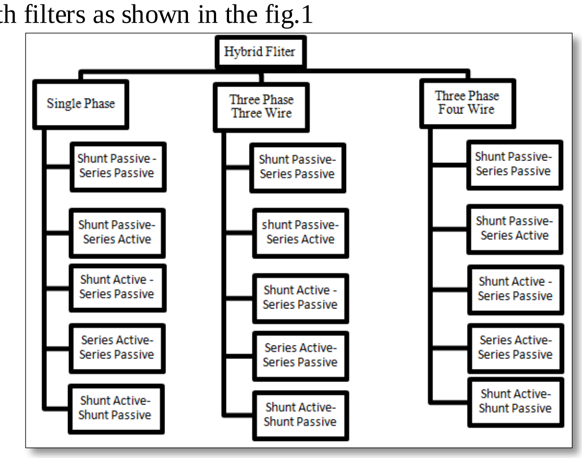

Fig.1: Hybrid Power Filter

SHPF presented in this paper consists of both Shunt APF (SAPF) and shunt PF. This filter effectively overcomes the weaknesses of a PF and APF. It offers low cost solution for the mitigation of harmonic of the huge NL. In this paper, to eliminate dominant order current harmonics such as 5^{th} and $7^{th}$from the system caused by the 3-phase uncontrolled bridge rectifier with inductive load SHPF is designed. Implementation of p-q theory is done for the controlling of

SAPF [8]. Comparison of results of both filters is made at the end of the paper.

II. SYSTEM CONFIGURATION

Fig. 2 represents block diagram of SHPF. A 3 phase diode rectifier is fed from 3 phase AC supply. A SAPF and PF are connected in parallel developing a circuit for filter design.

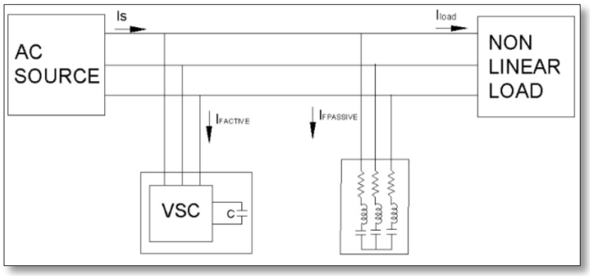

Fig.2: Block diagram ofSHPF

It offers effective mitigation of current harmonics with slight distortion in voltage supply. It consists of voltage source converter with capacitor connected at input end and output terminals are connected to AC system. 3 phase RLC series branch tuned for harmonic frequency is also connected in parallel with the system. To offer low impedance path for harmonic component, the SAPF adds current equal and out of phase to harmonic current and PF tuned and AC supply delivers the load current's fundamental partonly.

III. SHUNT HYBRID FILTER DESIGN

Designing of SHPF consists of designing of 1. Shunt PF 2. Shunt APF 3. Control Theory for SAPF

1. Shunt Passive Filter Designing :

It is a passive circuit consists of capacitors, inductors and resistors which screen the harmonic currents from the NLs. Single tuned PF is most commonly utilized for industrial application to mitigate the current harmonics. Most attractive features of this filter are low-cost and simple in designing compared with other filters.

Shunt PF filter is connected in parallel with the supply system and provides impedance path as low as possible for the current having frequency other than fundamental frequency. For Single tuned filter the resonance frequency is given as;

$$fr = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

Step 1: Estimate the 3-phase capacitive reactive VArs. (*Qc*).

Step 2: Calculate the capacitive reactance (*Xc*),

$$Xc = \frac{V^2}{Qc} \qquad (2)$$

$$C = \frac{1}{2\pi f Xc} \qquad (3)$$

V = RMS value of Line voltage

f = Supply frequency

Step 3: Calculate the inductive reactance (X_L) and inductance (*L*).

$$XL = \frac{Xc}{\square n^2} \qquad (4)$$

$$L = \frac{XL}{2\pi f} \qquad (5)$$

h_n = The harmonic order

Step 4: For the particular value of quality factor ranging from 30 to 50, Calculate the resistance (*R*).

In this work higher value of Q is selected to minimize energy loss and oscillations.

$$R = \frac{Xn}{Q} \qquad (6)$$

$$Xn = \sqrt{XLXC} \qquad (7)$$

Xn = The characteristic reactance

The values of *C*, *L* and *R for 5th and 7th Harmonic* were calculated based on the above equations (2)- (7) and circuit is designed.

2. Shunt Active Filter Design:

SAPF are ideal for current harmonic mitigation. Also, they havecapability of reactive power balance.

From the fig.2 NL is fed from3 phase supply with the APF connected in parallel. I_S is the supply current, I_{Load} is load current & I_{Active} is compensating current. It adds current which is identical in magnitude to the harmonic current but180°out of phase to cancel the effect of load current harmonics so that the sine wave of current is obtained.

3. Control Algorithm of SAPF:

SAPF is controlled by using Instantaneous Reactive Power Theory also called as p-q theory. It is ideal for elimination of current related PQ issues. In this algorithm Voltage & current are transfer from ABC frame to stationary reference frame.3-phase load voltages and load currents are converted into two-phase α–β orthogonal coordinates and then the instantaneous active power and reactive power consumed by load are computed.

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} Vas \\ Vbs \\ Vcs \end{bmatrix} \qquad (8)$$

$$\begin{bmatrix} iL\alpha \\ iL\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} ILa \\ ILb \\ ILc \end{bmatrix} \qquad (9)$$

$$\begin{bmatrix} pL \\ qL \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} iL\alpha \\ iL\beta \end{bmatrix} \qquad (10)$$

$$pL = pLdc + pLac \qquad (11)$$

$$qL = qLdc + qLac \qquad (12)$$

Both powers have fundamental (dc) and fluctuating (ac) part. Fundamental load power is extracted by using LPF and the fluctuating power is separated. The reference 3 phase supply currents are calculated as

$$\begin{bmatrix} isa \\ isb \\ isc \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V\alpha & V\beta \\ -V\beta & V\alpha \end{bmatrix}^{-1} \begin{bmatrix} pL \\ qL \end{bmatrix} \quad (13)$$

Key benefit of with αβ0 conversion is separation of zero sequence components. In this method I_0 can be simply abolished from the system as α and β axes does not makes any impact on zero sequence component.

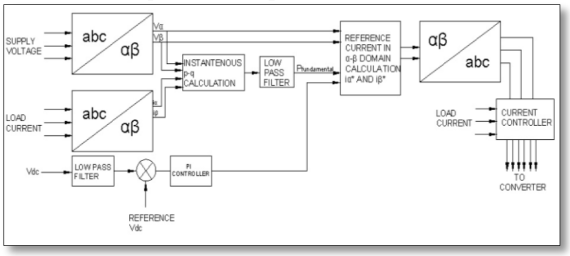

Fig.3: Control Algorithm p-q Theory

Actual current of the inverter and the reference currents found from equation (11) are equated and the gating pulses for the 3-phase inverter are generated from that error signals. From these equations SAPF is simulated with the help of embedded function block as shown in the fig.3.

4. Hysteresis current control :

Fig.4 shows the hysteresis current control scheme used for shunt active filter. i_{ref} is the reference for compensating current to be injected by active filter and i_{inj} is the actual current of active filter. Switching pattern of an active filter is decided by the control scheme. The switching pattern is arranged is such a way that it will maintain the actual injected current within the desired hysteresis band (HB) as shown in fig.4.

The switching logic is formulated as follows:

If $i_{inj} < (i_{ref} - HB)$ S_1, S_2 ON & S_3, S_4 OFF

If $i_{inj} > (i_{ref} + HB)$ S_1, S_2 OFF & S_3, S_4 ON

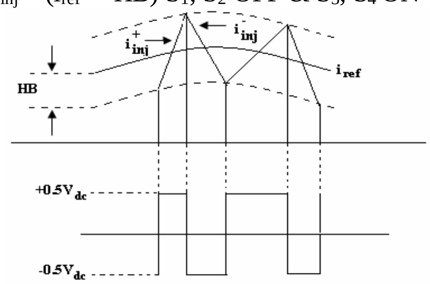

Fig. 4. Hysteresis current control

IV. SIMULATION AND RESULTS

The performance of the SAPF and SHPF has been tested in the MATLAB/Simulink environment. For this 3 phase rectifier is used as a NL and has been simulated for three cases 1. Without any compensation; 2. With SAPF and 3. With SHPF. The simulated results are discussed in following cases.

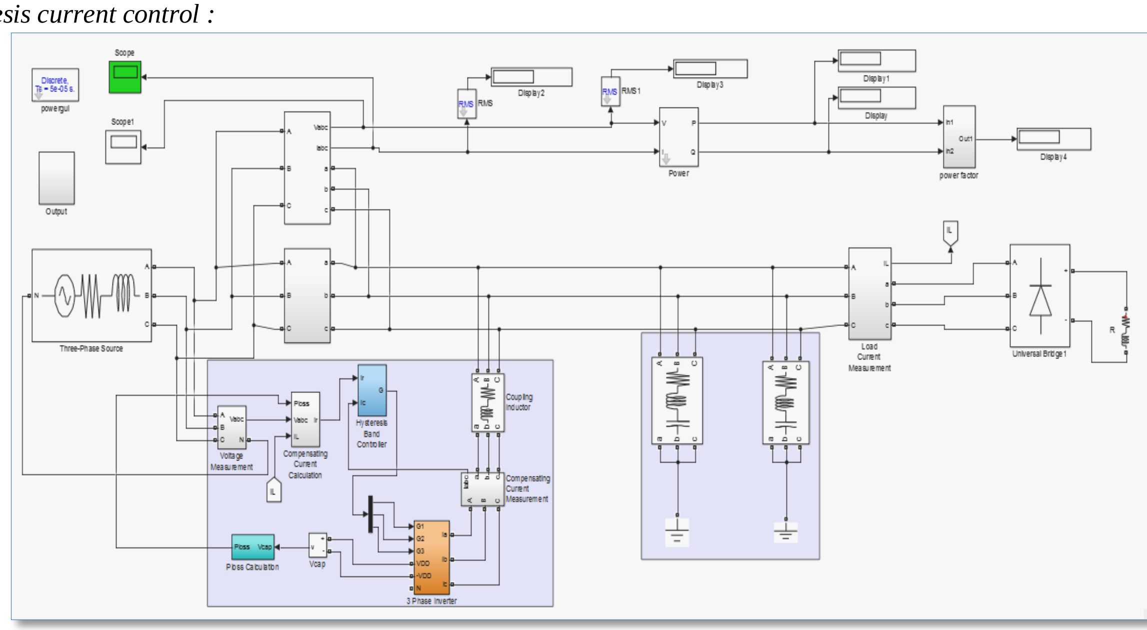

Fig.4: MATLAB Simulation

TABLE I. CIRCUIT PARAMETERS

Parameters	Values
Supply	415V, 50Hz
Source Impedance	R= 0.1 Ω, L = 0.15 mH
Load(R-L)	R= 60 Ω, L=20 mH
Line inductance	1 mH
Voltage source inverter	Split capacitors with each C = 35 µF

Case I: Without any compensation:

Fig.5 shows the supply current waveform, without a Filter. It clearly shows that that the current waveform Comprises of some non-linear correlation.

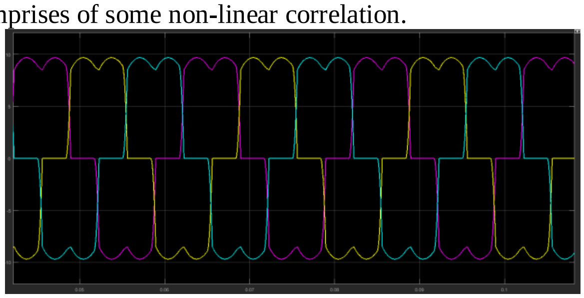

Fig.5: Load current waveform without filter

Fast Fourier transform (FFT) analysis is used to find out its frequency spectrum and the THD as shown in Fig.6.

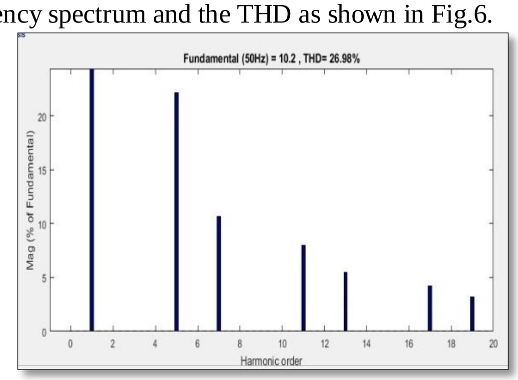

Fig.6: FFT Analysis

CaseI1: System Performance with SAPF:

The performance of the system with SAPF is determined. Fig. 7 shows frequency spectrum and THD after connecting SAPF.

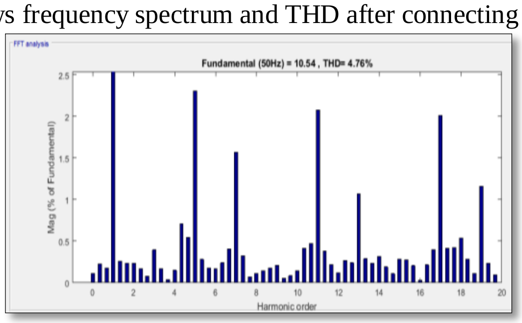

Fig.7: THD when active filter is connected

The waveform of load current, compensating current, supply current and supply voltage is shown in fig.8.

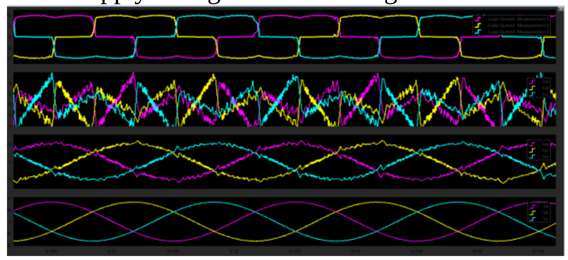

Fig.8: Waveforms of Load current, compensating current, supply current and supply voltage respectively (with SAPF)

With use of SAPF, the results for load current had been improved significantly and the percentage THD had been reduced as shown in fig.7.

Case2:System Performance with SHPF:

The performance of the system with SHPF is determined. Fig. 9 shows frequency spectrum and THD after connecting SHPF.

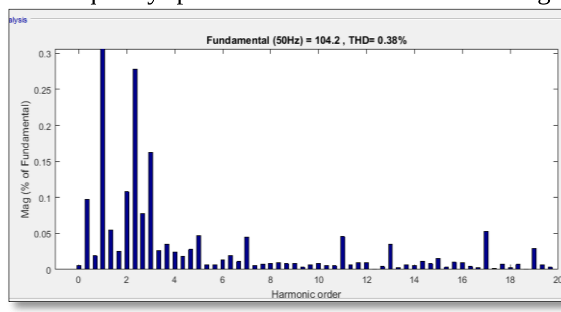

Fig.9: THD when Hybrid filter is connected

TABLE II. RESULT COMPARISON

Harmonics	Without Filter	With SAPF	With SHPF
5th	22.17%	2.31%	0.05%
7th	10.70%	1.57%	0.05%
%THD	26.98 %	4.76%	0.38%

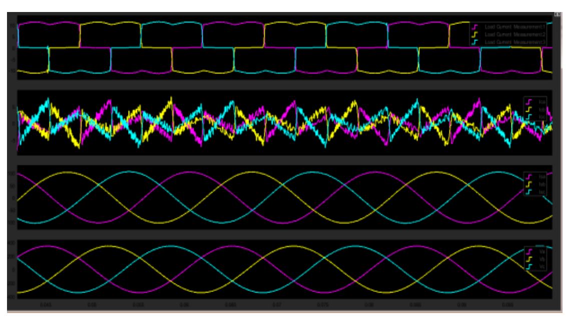

Fig.10: Waveforms of Load current, compensating current, supply current and supply voltage respectively (with SHPF)

The waveform of load current, compensating current, supply current and supply voltage is shown in fig.10. The current waveform has become smoother than that of SAPF waveform.

V. CONCLUSION

In this paper, SHPFis presented with a combinational operation of both passive and active power filter connected in parallel in the system.Simulation models were developed using MATLAB/Simulink for both filters and their results were discussed in detail.The results of SHPF were compared with the results of SAPF. Simulation results showed that the percentage THD is considerably reduced with the hybrid connection of the passive filter and APF. Specifically 5th and 7th Harmonic component are improved with 2.26% and 1.52% respectively.

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