Design and Implementation of Hybrid Active Power Filters for Power Quality Improvement in Industries

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Abstract— This paper presents design and simulation of a three-phase hybrid active power filter to eliminate the harmonics and for mitigation of the power quality problem at ac mains in ac-dc power supply feeding to a nonlinear load. The non linear loads take discontinuous current and thus it injects harmonics. The hybrid active power filter, which combines active power filter, passive power filter and generalized integrators, and which has their both respective merits, leading the development of electric reliability and quality. This harmonic distortion can be reduced by suppressing the harmonic resonance using the hybrid active filter, which is operated as variable harmonic conductance according to the voltage total harmonic distortion. Therefore, the harmonic resonance would be avoided as well as harmonic voltage distortion can be maintained at an allowable level. Finally, representative simulation results of a three phase hybrid active filter are presented to verify the effectivemess of HAPF in power quality enhancement.

Key words: Hybrid active power filter, Active power filter, Passive power filter, Harmonic resonance, Total harmonic distortion.

I. INTRODUCTION

With the increasing use of non-linear loads such as diode bridge rectifiers, adjustable speed-drives and cycle converters, the generation of harmonic currents has steadily increased and has heightened the interests in power quality [1]. In modern power system, power electronic devices are dominating the consumer end in both industrial and domestic region. Majority of these devices are non-linear in nature, results in injection of harmonics and draw reactive component of current. These non-linearities, if not controlled, may spread further in the whole system deteriorating the system performance [2-4]. Active power filters (APF) have shown to be an effective technology to eliminate harmonics and to compensate nonlinear loads [5-7]. The shunt connection has been the most studied topology, where the APF is connected in parallel with the load. One of its traditional uses is the elimination of current harmonics produced by loads which generates such disturbances, this is HCS loads (Harmonic Current Source) [8, 9]. However, the parallel APF is not suitable in situations where the load generates voltage harmonics, HVS loads (Harmonic Voltage Source). In this case, series connection APF configuration has been proposed and different control strategies have been tried out [10].Compensation systems composed only of an APF either shunt or series connection do not solve completely the problem of harmonic elimination for all load types. So, other configurations have been proposed [5]. They combine series and parallel topologies, active and passive filters. This paper proposes a hybrid active filter to suppress the harmonic resonance in industrial facilities as well as mitigate harmonic current flowing into the utility. The proposed hybrid active filter is composed of an active filter and a power factor correction capacitor in series connection. The active filter operates as variable damping conductance at harmonic frequencies. The harmonic conductance is determined according to the voltage total harmonic distortion (THD) at the installation location of the hybrid active filter. Based on this control, the damping performance of the active filter can be dynamically adjusted to maintain harmonic voltage distortion at an allowable level in response to load change and power system variation, where the allowable voltage THD can be regulated according to the harmonic voltage limit in IEEE std. 519-1992 [11]. Since the series capacitor is responsible for sustaining the fundamental component of the grid voltage, the active filter can be operated with a very low dc bus voltage, compared with the pure shunt active filter [12]. This feature is a significant advantage, in terms of both the rated kVA capacity and the switching ripples of the active filter.

II. ENHANCEMENT OF POWER QUALITY IMPROVEMENT USING HYBRID POWER FILTER

The schematic diagram of the shunt hybrid power filter (SHPF) is presented in Fig. 5. This circuit contains the three phase supply voltage, the three phase diode. rectifier and the filtering system consists of a small-rating active power filter connected in series with the LC passive filter. This configuration of hybrid filter ensures the compensation of the source current harmonics by enhancing the compensation characteristics of the passive filter besides eliminating the risk of resonance. It provides effective compensation of current harmonics and limited supply voltage distortion. The hybrid filter is used to control such that the harmonic currents of the nonlinear loads flow through the passive filter and that only the fundamental frequency component of the load current is to be supplied by the ac mains.

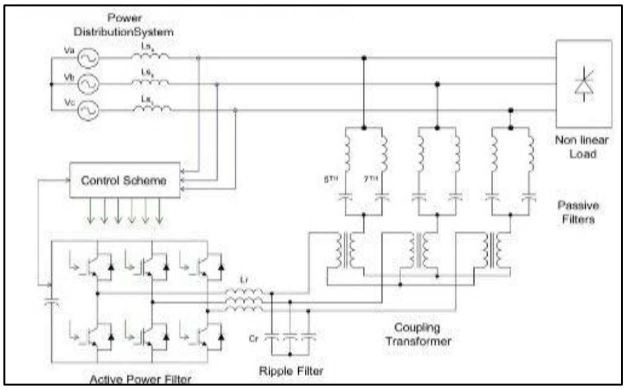

Fig. 1: Circuit diagram of the HAPF

In this paper, we further present designing consideration of the hybrid filter. A prototype circuit of the hybrid filter based on 220-V/10-kVA system has been established to verify theoretic analysis, including steady-state behavior, transient response, and stability analysis. The filtering performance of the hybrid filter is discussed considering X/R ratio and magnified varia- tions of line impedance. We also focus on filtering deterioration due to line resistance, voltage unbalance, and capacitive filters in the power system. In many cases, an active power filter is designed to compensate harmonic current produced by a specific nonlinear load, in such a way that it needs to measure the load current to be compensated. In this paper, the active filter is designed as a harmonic conductance to suppress both harmonic resonance and harmonic distortion by using inverter-side voltage and current measurements. Notice that it does not require current information of the nonlinear loads. Thus, this approach can be suitable in power distribution networks in which the loads may be distributed along a feedeIn addition, compensating fundamental reactive power due to unbalanced load is possible, but it is outside the scope of this paper.

III. POWER QUALITY IMPROVEMENT USING HYBRID POWER FILTER

A. *Passive Filter*

Passive filters are applied either to shunt the harmonic currents off the line or to block their flow between parts of the system by tuning the elements to create a resonance at a selected harmonic frequency.

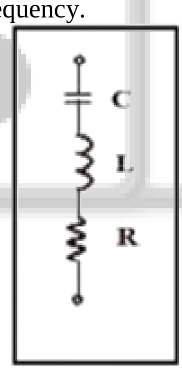

Fig. 2: Single tuned passive filter

The passive filter used here is the single tuned passive filter which is shown in Fig.2. It is the simplest and easy to construct among all shunt passive filters. In this filter the inductor and capacitor are designed to mitigate a particular order of frequency by providing a low impedance path. The design of passive filters is very simple and economical compared to active filters. The filter parameters designed for the proposed work is based on (1) to (5), and discussed in [].

Reactive Power, kV AR

$$kVAR = kVA * \sin(\cos^{-1} (PF)) \quad (1)$$

Filter Reactance

$$X_{fil} = \frac{kV^2 (1000)}{kVAR\pi} \ \Omega \quad (2)$$

Capacitive Reactance

$$X_{cap} = \frac{X_{fil} * h^2}{h^2 - 1} \ \Omega \quad (3)$$

Inductive Reactance

$$X_L = \frac{X_{cap}}{h^2} \ \Omega \quad (4)$$

Harmonic Frequency

$$f_h = \frac{1}{2\pi\sqrt{LC}} Hz \quad (5)$$

Where,
h - Harmonic order
L - Inductance (H)
C - Capacitance (F)

B. *Design of Active Power Filter*

A voltage source inverter is used as the active power filter, for which the input DC voltage is essentially constant and independent of the load current drawn [14-15]. A large capacitor is placed across the DC input line to the inverter. The capacitor ensures that any switching event within the inverter do not significantly change the DC input voltage. On the AC side of the VSI, ripple filter is connected, which compensates for the ripples generated in the APF current due to fast switching of MOSFETs.

1) *Selection of Lc, Cdc, Vdc*

To keep harmonic distortion in source current within limits, a desirable condition is that the DC bus voltage across the capacitor should rise up to around double the peak source voltage [15]. This choice makes the transient response of the active filter better, as capacitor has sufficient stored energy to meet the requirement of sudden load changes. While deciding rating of DC link capacitor following points are to be considered-

1) Power factor close to unity should be achieved with any type of load,
2) A constant DC voltage should be maintained across the capacitor with minimum ripples,
3) Steady state as well as transient response must be fast.

The DC bus capacitance of the APF system can be calculated from the energy requirement of the capacitor [14]-

$$\Delta e_{dc} = \frac{1}{2}\left[\left(V_{dc}^{*}\right)^2 - \left(V_{dc}\right)^2 \right] \quad (6)$$

$$L_c \frac{di_c}{dt} = -v_c + v_s = V_c + V_{sm}$$

Here Δe_{dc} is the energy required by the capacitor to be stored for keeping the DC bus voltage near reference value.

Design of filter inductance (R_c, L_c) depends upon the switching frequency of the hysteresis band current controller. The APF circuit can be represented by equation-

$$R_c i_c + L_c \frac{di_c}{dt} + v_c = v_s \quad (7)$$

Where *vc* is the voltage at the VSI-mid point. Average value of *vc* is assumed equal to the addition of votlage *vs* and voltage drop across ripple filter (Lc, Rc). Voltage drop across inductor of the ripple filter is considered to be around 10% of the supply voltage, drop across resistance Rc is very small compared to that across Lc and therefore can be neglected.

Thus the equation (14) becomes-

$$L_c \frac{di_c}{dt} = -v_c + v_s = V_c + V_{sm} \quad (8)$$

Lower value of ripple filter inductance is selected for taking into account the variation in switching frequency. Hysterisis bandwidth of controller is taken as ±0.2. Calculated values of *Cdc*, *Vdc* and *Lc* and nearer values are implemented on the system and system performance judged on parameters like power factor, transient response and %THD.(table 1.1)

V_i (3 phase)	415 V
L_s	0.01 mH
f	50 Hz
C_{dc}	3000 mH
V_{dc}	325 V
L_f	5 mH
Transformer Ratio	1:1 N_P/N_S= 230V/230V, 50Hz
Nonlinear Load	R=20mho, L=25mH

Table 1: System Parameters

IV. SIMULATION RESPONSE

A. *Simulation Response without Filter*

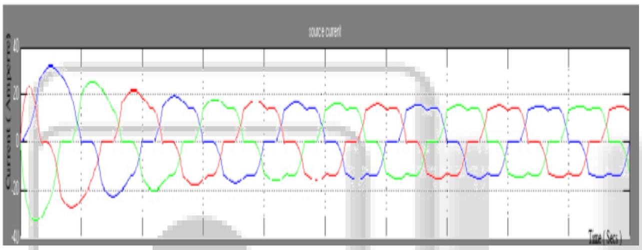

Fig. 3: (a) Waveforms of source voltage without filters

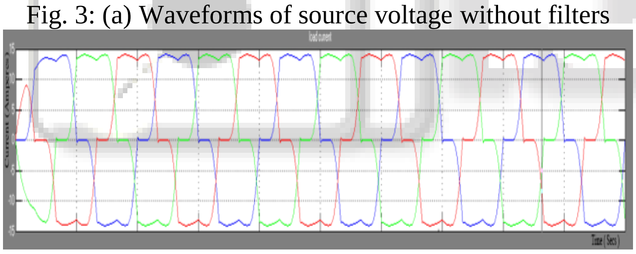

Fig. 4: (b) Waveforms of load current without filters

1) *FFT Spectrum*

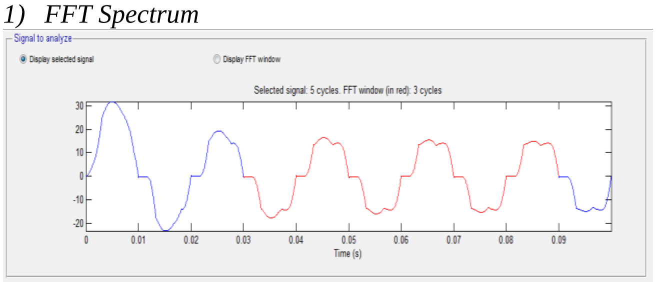

Fig. 5: (a) AC main current with R-L load

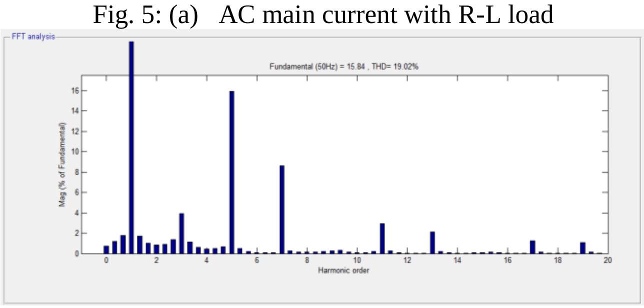

Fig. 6: (b) AC mains voltage response with %THD

B. *Simulation Response with Filter*

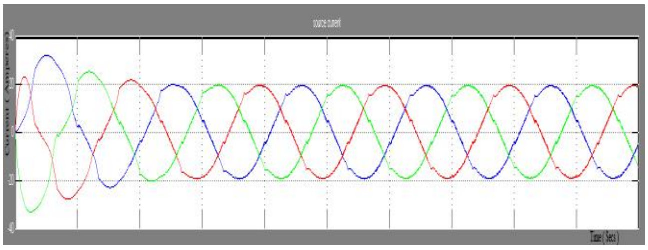

Fig. 7: (a) Waveforms of source voltage with filters

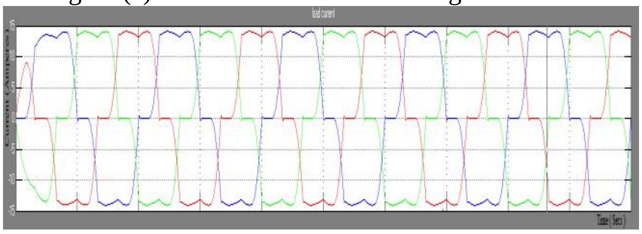

Fig. 8: (b) Waveforms of load current without filters

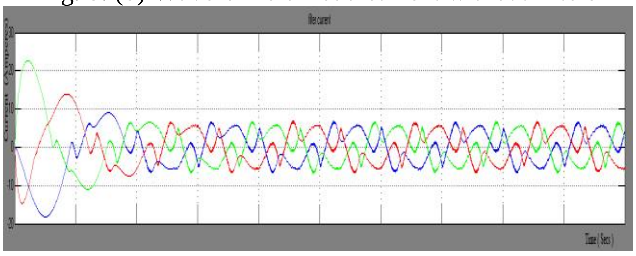

Fig. 9: (c) Waveforms of Filter Current with HAPF

1) *FFT Spectrum*

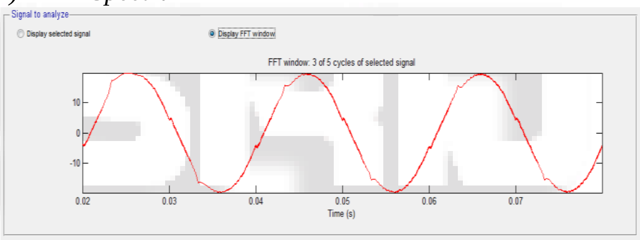

Fig. 10: (a) AC main current with R-L load

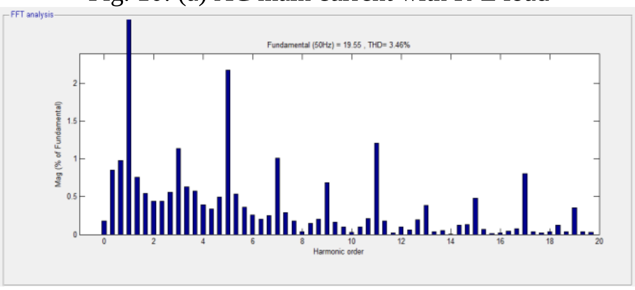

Fig. 11: (b) AC mains voltage response with %THD

The THD when hybrid active filter is connected to the grid network is shown approximately 3.46% for a selected start time and number of cycles. This percentile THD value is low so that it is clearly understood the number of harmonics in the system is reduced and hence the power quality of the system is improved.

V. CONCLUSIONS

This paper works on the present design of the shunt passive filter and the shunt hybrid power filter for a distribution system. The hybrid filter reduces the harmonics as compare to the open loop response. This hybrid filter is tested and verified using MATLAB program. It has been shown that the use of hybrid active power filter helps in reducing the harmonics produced in the system due to the nonlinear loads. The performance of the proposed system has been verified by simulation results. The major goals were to compensate the load reactive power and current harmonics generated by the current source types of non linear load. The THD under the current source type of non linear load has been reduced for delta connection from 19.02% to 3.46%.

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