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Enhancement of Power Quality with Shunt Active Power Filter for Domestic Applications

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ABSTRACT: Consumer electronics, domestic appliances and a large range of industrial applications, namely power electronics based, can cause high disturbances in the supplied electricity. Normally soft starts are used for avoiding this problem and to achieve smooth starting of large capacity induction motors. A 3- phase AC voltage controller is employed as a soft-start. But, this takes harmonic-rich current especially while operating at large firing angles. In this paper, the effect of inserting a shunt active filter to provide harmonic and reactive power compensation in a soft-start has been studied. The shunt active filter has been inserted between the AC voltage controller and power supply to take care of the reactive power requirement of the motor and AC voltage controller and also to provide harmonic compensation. Therefore, as a result of theses harmonics, a traditional passive filters are used to suppressed the integer multiple fundamental frequencies, but due to the passive filter draws back in producing series or parallel impedance with the supply impedance and heavy in sized, its limitations in service becomes an old scheme. The application of shunt active power filter in mitigating these harmonics problems supersedes the used of passive filter.

KEYWORDS:*APF, THD, PQ, DC, PF, PI Controller.*

I. INTRODUCTION

The use of non-linear loads at the consumers end in the form of power electronic converters, UPS, electric arc furnaces, and growing use of adjustable speed motor drives is increasing day by day[1][2][3]. These power electronic loads inject harmonic currents and reactive power into the supply grid having significant impact on voltage and power quality, thus polluting the electric distribution network and also effect the operation of power electronic interface [4]. The presence of harmonics due to widespread use of power electronic loads results in an increased deterioration of the power systems voltage and current waveforms, because of line impedance, the voltage at the point of common coupling (PCC) is no longer remains sinusoidal [5]. The impact of non-linear loads on distribution power system. With a network then dominated by nonlinear components (power electronics coupling for generators and loads), non-sinusoidal regimes will be a common situation. It will be then the task of the power electronics interfaces to provide for the control features that can achieve an acceptable level of power quality required by the system operator or standards (given sensitive loads connected to the system).

A Passive filter is designed with only inductors, capacitors and resistors, so that it is less expensive. Based on the harmonic source present the design of passive filter will change accordingly. Active filters are easy to tune, and they are small with less weight and can produce a high gain. Active filters contain power electronic devices so that harmonics can be distorted easily. In this paper, single phase active filter is used to reduce the harmonics which are present in the system [6], [7].

The traditional reduced voltage starting methods, such as star-delta starting and impedance starting, result in stepped variation of voltage whereas a soft-start increases the voltage applied to the induction motor in a smooth manner. A 3-phase AC voltage controller is normally employed as a soft-start. However, the output of an AC voltage controller is rich in voltage and current harmonics which results in derating of the induction motor [10],[11].

II. BASICS OF FILTER CONFUGARATION

Harmonic distortion in power distribution systems can be suppressed through three basic approaches namely:

(1) Passive filter.

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(2) Active power filter.

A. PASSIVE FILTER

The passive filtering is the simplest conventional solution to mitigate the harmonic distortion. Passive filters are inductance, capacitance, and resistance elements configured and tuned to control harmonics. The second-order HPF is the simplest to apply while providing good filtering action and reduced fundamental frequency losses.

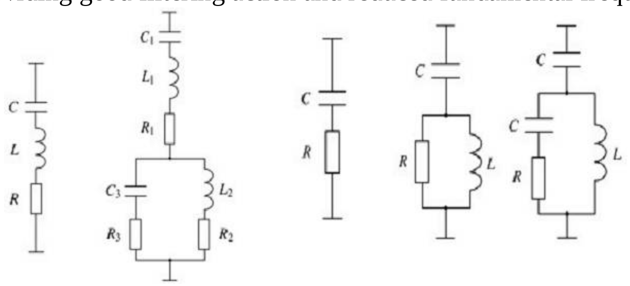

Figure.1. Various Configurations of Passive Filters

The filtering performance of the third-order HPF is superior to that of the second-order HPF. The filter components are very bulky because the harmonics that need to be suppressed are usually of the low order. The passive filter is also known to cause resonance, thus affecting the stability of the power distribution systems.

B. Active Filter

The basic principle of APF is to utilize power electronics technologies to produce specific currents components that cancel the harmonic currents components caused by the nonlinear load. APF can be connected in several power circuit configurations as illustrated in the block diagram shown in Fig.2.

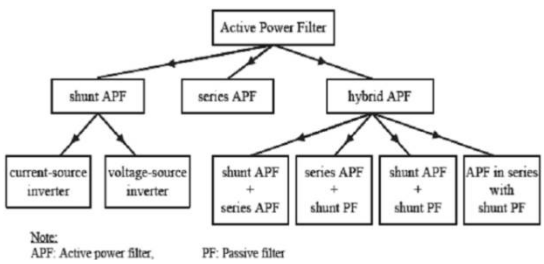

Figure.2 Sub division of APF according to power circuit configuration and connections

They can suppress not only the supply current harmonics, but also the reactive currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems.

1) SHUNT ACTIVE POWER FILTER

This is most important configuration and widely used in active filtering applications. A shunt APF consists of a controllable voltage or current source. The voltage source inverter (VSI) based shunt APF is by far the most common type used today, due to its well-known topology and straight forward installation procedure. Fig.3 shows the principle configuration of a VSI based shunt APF. The operation of shunt APF is based on injection of compensation current which is equivalent to the distorted current, thus eliminating the original distorted current.

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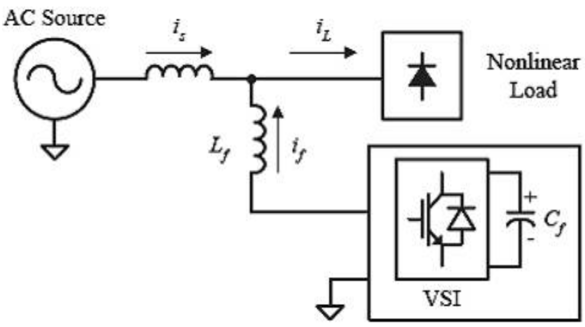


Figure.3 Principle configuration of VSI based shunt APF.

2) Series Active Power Filter

The series APF is shown in Fig.4. It is connected in series with the distribution line through a matching transformer.

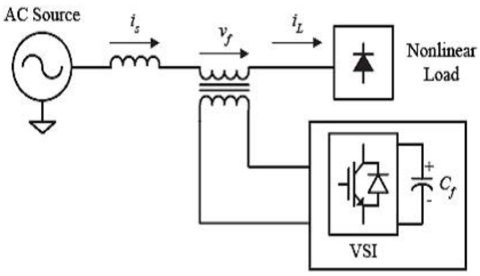
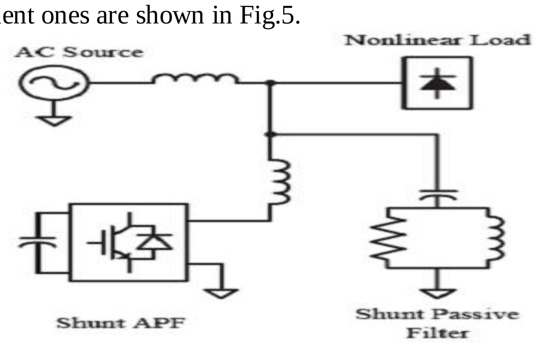


Figure.4 Principle configuration of VSI based series APF.

VSI is used as the controlled source, thus the principle configuration of series APF is similar to shunt APF, except that the interfacing inductor of shunt APF is replaced with the interfacing transformer as in fig.4. The operation principle of series APF is based on isolation of the harmonics in between the nonlinear load and the source. This is obtained by the injection of harmonic voltages (V_f) across the interfacing transformer.

3) HYBRID ACTIVE POWER FILTER

Technical limitations of conventional APFs mentioned above can be overcome with hybrid APF configurations. They are typically the combination of basic APFs and passive filters. Hybrid APFs, inheriting the advantages of both passive filters and APFs provide improved performance and cost-effective solutions. The idea behind this scheme is to simultaneously reduce the switching noise and electromagnetic interference. There are various hybrid APFs reported in literature, but the two most prominent ones are shown in Fig.5.



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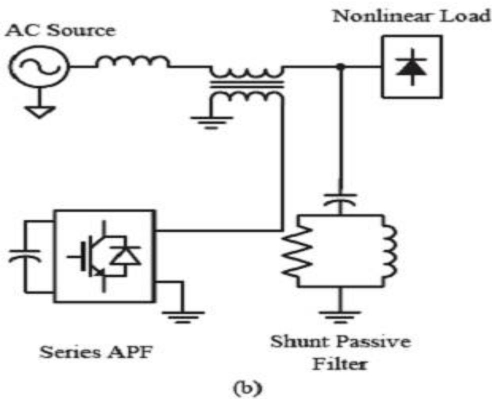

Figure.5 Hybrid APF (a) Combination of shunt APF and shunt passive
(b) Combination of series APF and shunt passive

III.SHUNT ACTIVE POWER FILTER

The shunt-connected active power filter, with a self controlled dc bus, has a topology similar to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal- but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase- shifted by 180°.

A. BASIC COMPENSATION PRINCIPLE

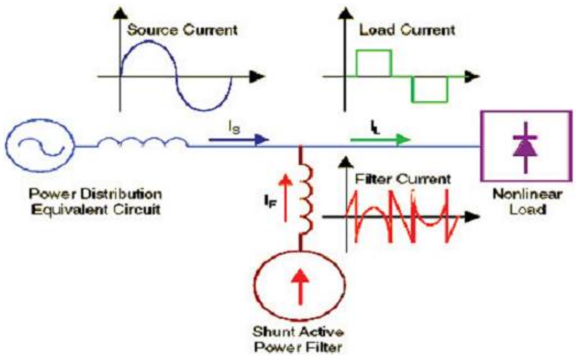

Figure.6 Basic Compensation Principles.

Fig.6 shows the basic compensation principle of a shunt active power filter. It is controlled to draw/supply a compensating current I from / to the utility, so that it cancels current harmonics on the AC side, and makes the source current in phase with the source voltage. The load current waveform, the desired mains current and compensating current injected by the active filter are containing all the harmonic components to make mains current sinusoidal.

B. ESTIMATIONOF REFERENCE CURRENT

The theory of the instantaneous reactive power also known as p-q theory has been introduced by Akagi [8] et al, in 1983. This theory allows the separation of the power components in mean and oscillating values, assuring the separation of the undesired components which should be supplied by the Active Power Filter. The involved mathematical calculations to determinate the compensation currents can be completely executed with digital operations and implemented in low cost microcontrollers. To apply this theory in single-phase systems, it is possible to consider a balanced three-phase system were the phase a corresponding to the single-phase system and the other phases.

$$i_a = \sum^{n} \sqrt{2} I_i \bullet \sin(\omega_i + \theta_i) \tag{1}$$

Assuming that this current is the phase a current, in a three-phase equilibrated system, and then the corresponding b and c phase currents can be represented by following equation:

$$i_b = \sum_{i=0}^{n} \sqrt{2} I_i \bullet \sin(\omega_i + \theta_i - 120^o) \tag{2}$$

The compensation current in the a-b-c reference frame is determined by

$$i_{comp} = \sqrt{\frac{2}{3}} \bullet i_{ca} \tag{3}$$

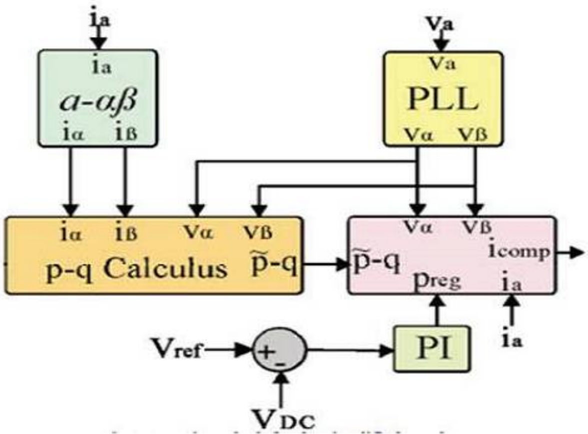

Figure.7 Block diagram of p-q based control

1) Mean Power Theory

To apply this theory is necessary to calculate the average active power consumed by the load. Then the average value is divided by a constant value that represents the mean voltage at the system, giving the amplitude of the ideal current on the source. The average power is calculated by the multiplication of the instantaneous value of the load current by the instantaneous value of the system voltage.

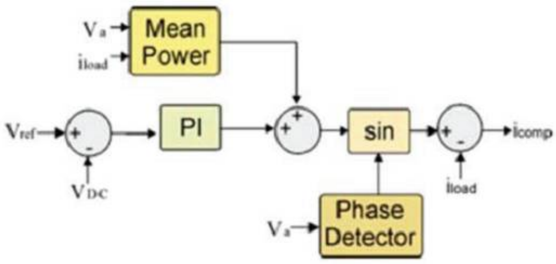

Figure.8 Block diagram of mean power control

2) Hysteresis Control Technique

The control of APF can also be realized by the hysteresis control technique. It imposes a bang-bang type instantaneous control that forces the APF compensation current (i_f) or voltage (V_f) signal to follow its estimated reference signal (i_{fref} or v_{fref}) within a certain tolerance band. This control scheme is shown in a block diagram form in Fig .9.

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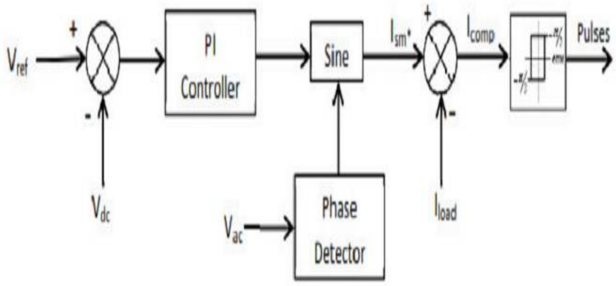

Figure.9 Block diagram of hysteresis current controller.

V.MATLAB/SIMULINK RESULTS

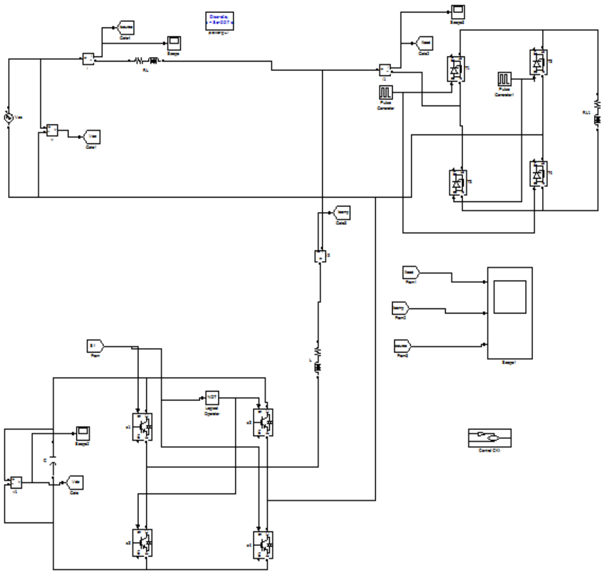

Figure .10. Simulink model of APF using HCC for rectifies as a non-linear Load.

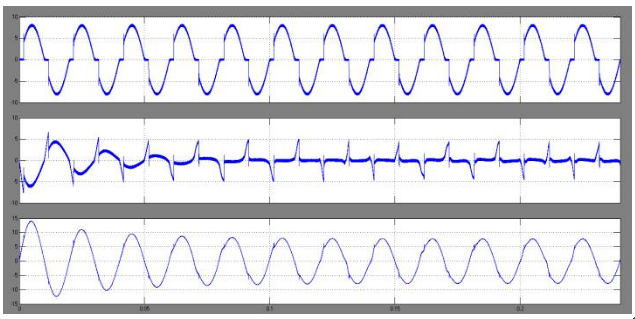

Figure.11. Load, Compensation & Source Current for Į = 30^{o}

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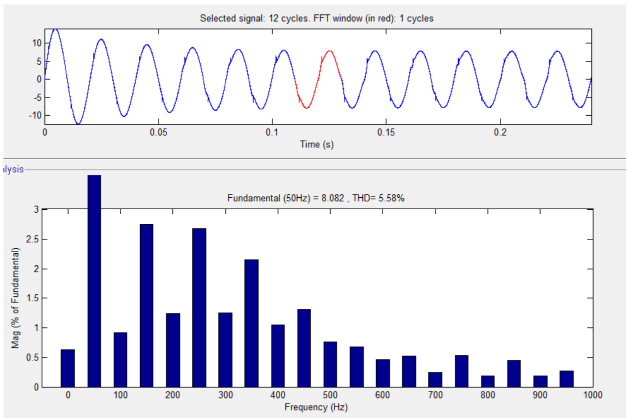

Figure.12. FFT analysis of source current with APF for Ị = 30°.

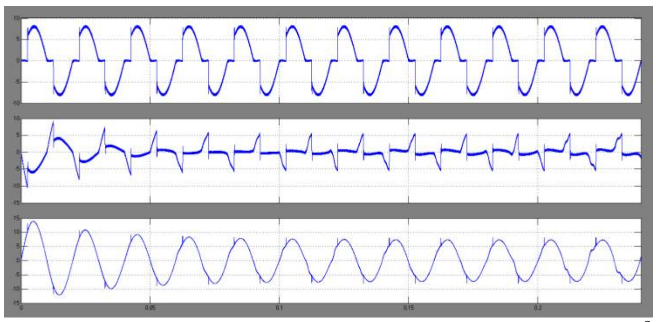

Figure.13. Load, Compensation & Source Current for Ị = 45°

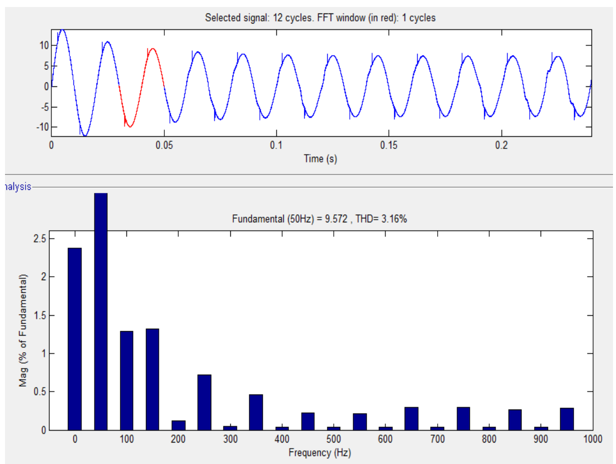

Figure.14. FFT analysis of source current with APF for Ị = 45°

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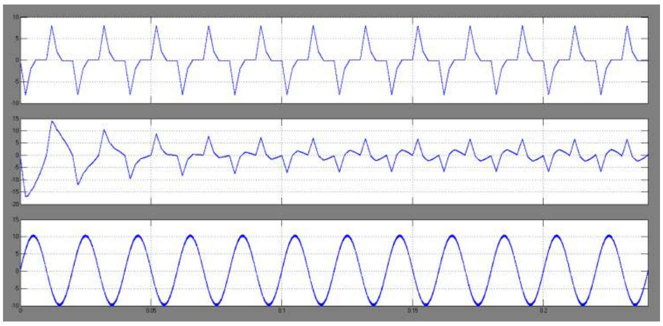

Figure.15. Load, Compensation and Source Current for CFL as a Load.

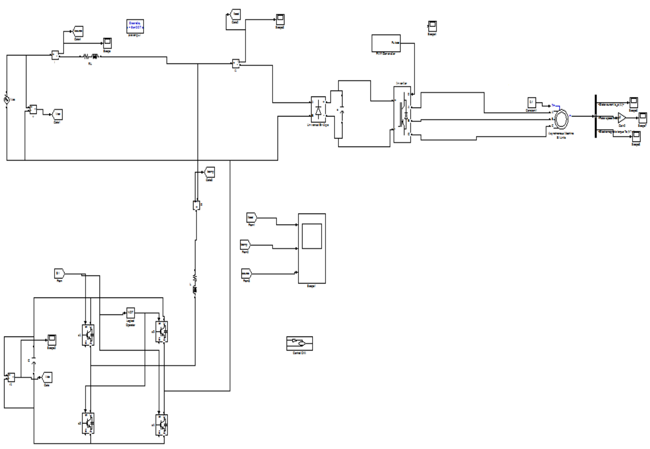

Figure.16. Simulink model of APF using HCC for rectifies as a non-linear Load with Induction Motor Drive.

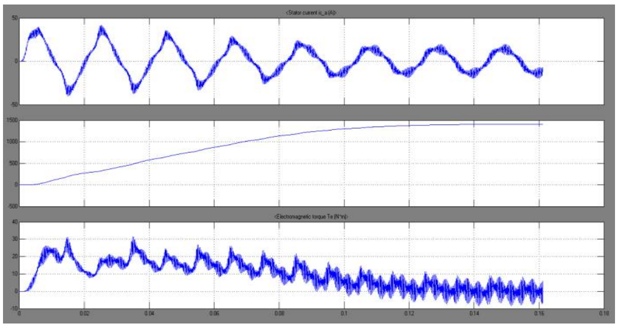

Fig.17.Simulation Results of Current, Speed and Torque for Induction Motor Drive.

VI.CONCLUSION

The presented single-phase Shunt Active Power Filter has demonstrated to be able to compensate the harmonic currents and the power factor produced by loads, making the current at the source side to become almost sinusoidal and in phase with the system voltage. This current compensation can also prevent voltage harmonics. APF simulation using MATLAB Simulink is proven to be very useful for studying the detailed behavior of the system for harmonic and unbalance compensation, under steady state and transients. In all, it can be stated that a shunt active filter can be very useful to reduce the current amplitude and Pollution level substantially when an AC voltage controller fed induction motor drive is employed in certain applications like fans or centrifugal pumps. This will be a very useful scheme especially in industries where multiple induction motors of large capacity are frequently started from a 3-phase supply.

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BIOGRAPHY

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