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ENHANCEMENT OF POWER QUALITY USING A ROBUST HYBRID SERIES ACTIVE POWER FILTER

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ABSTRACT: In this paper, Design of Hybrid series active power filter (HSAPF) for Harmonic reduction and reactive power compensation in single phase systems is represented. The HSAF consists of the series combination of two single tuned LC filters which are tuned to 3^{rd} and 5^{th} harmonics and an active filter. Discrete Fourier transformation is used as the control technique. Simulation results using MATLAB shows the effectiveness of control technique. On getting the simulation results the value of THD is very low (2.75%), which is very negligible. So the power quality is said to be improved.

Keywords: Hybrid series active power filter, active filter, harmonic reduction, reactive power compensation, Discrete Fourier transformation, power quality.

I.INTRODUCTION

With the wide use of power electronic equipments and nonlinear loads, the power quality has been lost in distribution system. Current harmonics cause serious harmonic problems in distribution feeders for sensitive consumers. Some technology solutions have been reported in order to solve power quality problems. Initially, lossless passive filters have been used to mitigate harmonics and for compensation of reactive power at nonlinear loads. However, passive filters have the drawbacks of fixed compensation, large size and resonance with the supply system.Active filers have been explored in shunt and series configurations to compensate different types of nonlinear loads; nevertheless, they have some demerits. As a case in point, their power rating is sometimes close to load, and thus it becomes a costly option for power quality improvement. Many analysts have classified various types of nonlinear loads and have suggested different filter options for their compensation. In response to these factors, a series of hybrid filters has been evolved and widely used in practice as a cost effective solution for the compensation of nonlinear loads. Mainly shunt active filters consisting of voltage-fed pulse width modulated (PWM) inverters using IGBT or GTO thyristors are operating successfully in all over the world. These filters provided the required harmonic filtering, reactive power compensation, and etc [1-2].

The most important technology for the power quality improvement is the detecting method of harmonics to decrease the capacity of the various energy storage components. Different control methods are presented in recent publications for this type of active filters [3-16].The control method presented in this thesis is depends upon the calculation of the real part of the fundamental load current while this is helpful in some configurations such as hybrid series active filter, since it cannot compensate reactive power completely and needs many complicate calculations. The active power filter proposed in this thesis uses a dc capacitor voltage closed- loop control and used a modified phase-locked loop for extraction of

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the reference current. In the cited references, the computation involves various control parameters or needs complex calculations. Also, the dynamic performance of the compensator is not desire in the case of fast-changing loads. The least compensation current control method presented in [9] is based on detection of the harmonics and reactive current of the active power filter. In [10], genetic algorithm and extended analysis optimization techniques were applied for switched capacitor active filters. The combined genetic algorithm/conventional analysis control methods [11] have been considered as a recent control approach. These control methods have a common demerit of concerning the global stability of the closed- loop system. In [12], the control technique is based on the calculation of average power; this wants to know some information regarding system and requires some intense calculation. The sliding-mode control technique proposed in [13] solves the stability problem; however, the calculation technique for compensation of current reference is complex and switching rate is variable. In [14], a digital repetitive control approach is presented to obtain high gain for the current loop; nevertheless, the control strategy in this method is based on a linearized replica of the active filter and does not direct to global stability. A deadbeat control strategy is presented in [15] for the current loop of single-phase active filters. Even though this process has a rapid current control due to the deadbeat nature, it dependence on parameters is a basic drawback. Furthermore, the call for prediction of the current reference requires adaptive signal processing techniques, complicating the execution of this technique. Passivity based controllers [16] based on phasor models of system dynamics have also been projected in an attempt to improve the stability properties of active filters.

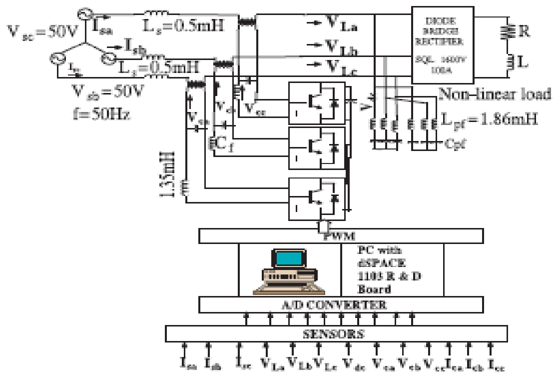

Fig 1. Schematic diagram of the control and power circuit of the HSAPF.

This paper uses a Discrete Fourier transform for single phase active power filters (APF) that is organized as follows: section II show the hybrid series active power filter (HSAPF) pattern for harmonic reduction and reactive power compensation; Section III presents the control method; section IV shows stability study of the proposed pattern; section V shows frequency response of the projected pattern; section VI presents the simulation outcome of this technique for a hybrid series active filter, and section VII presents the experimental outcome of this method for a HSAPF.

TABLE I. System parameters used in simulations

Parameter	Values
Power source voltage : V_s(V)	220
System equivalent inductance: L_s(mH)	0.48
Load input inductor: L_{AC}(mH)	3
Filter capacitor of 3rd: C_{3f}(µf)	25
Filter inductance of 3rd: L_{3f}(mH)	45
Filter capacitor of 5rd: C_{5f}(µf)	25
Filter inductance of 5rd: L_{5f}(mH)	16
dc capacitor: C_{dc}(µf)	1500
Load capacitor: C_L(µf)	2100
Load resistance: R_L(Ω)	40
Power system fundamental frequency : (Hz)	50

Fig. 1 shows the pattern of the HSAPF and nonlinear load planned in this paper and, its parameters are given in Table

I. the HSAF consists of a series combination of an active filter and two parallel single tuned passive filters. Two passive filters are tuned in dominants harmonic frequencies of

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3rd and 5th. The effectiveness of the proposed method in harmonic elimination and reactive power compensation is shown using HSAF for a non linear load. In the following sections control method and design process and simulation results are given.

II.HYBRID SERIES ACTIVEPOWERFILTER (HSAPF) FOR HARMONIC REDUCTION

The active filters are divided into pure active filters and hybrid active filters in terms of their circuit pattern. Most pure active filters in their power circuit use either a voltage-source pulse width-modulated (PWM) converter set with a dc capacitor or a current-source PWM converter set with a dc inductor. At present, the voltage-source converters are more positive than the current-source converters in terms of cost, physical size, and efficiency. A hybrid active filter consists of single or multiple voltage-source PWM converters and passive elements such as capacitors, inductors, and/or resistors. The hybrid filters are more favorable than the pure filters in harmonic reduction from both feasibility and economical points of view, particularly for high-power applications. However, single-phase active filters attract much less attention than three- phase active filters because single phase versions are restricted to low-power applications except for electric traction or rolling stock [17].execution of an APF is to use a consistent method for current/voltage reference generation. Presently, there is a great variety of practical achievement supported by various theories.

III.COMPENSATION STRATEGY

The control technique has to extract the harmonic components with minimum phase shift and attenuate the fundamental component. In this paper discrete Fourier transformation (DFT) is used to extract the source current harmonics with assuming N samples in a cycle, as

$$X_1 = \sum_{k=0}^{N-1} x_k e^{\frac{j2\pi k}{n}}$$

$$x_{k1} = \frac{1}{N} X_1 e^{\frac{-j2\pi k}{N}}$$

Where upper equation is DFT and lower equation is inverse DFT. After extracting the fundamental component, it is subtracted from source current to get harmonic components as:

$$i_{Sh} = i_S - i_{S1}$$

Fig. 2 represents the control circuit. If active filter is placed along the passive filter, an extra voltage reference is added to q component. As seen from this figure, a component with 90 degree lead the load terminal voltage is summed to reference voltage to control the dc link voltage capacitor.

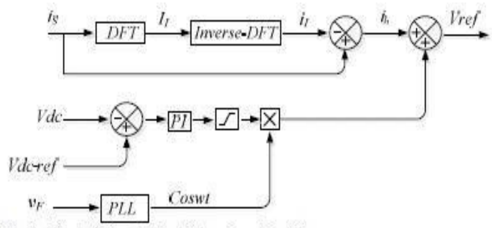

Fig. 2. Control circuit of hybrid series active filter.

IV.POWER SYSTEM STABILITY ANALYSIS

Fig. 3 shows entire power system block diagram. Active filter shows zero impedance against fundamental component of the source current while it shows very high impedance against harmonics. In Fig. 3, analog to digital converters which are placed in the control circuit give some delays in system. Also, it takes a little bit of time to take out harmonic components by the

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microcontroller. Assuming that all the delays in the system as τ, Fig. 4 shows the system control diagram. So, the open-loop transfer function will be as:

$$G(s) = \frac{K}{sL + Z_F} e^{-s\tau}$$

Above equation represents that if τ is zero, the system is always stable. However, the noise is not eliminated. Fig. 5 represents the relationship between system critical time (τ) and system impedance for various values of K. As seen in from this figure, as K increases, the system critical time is decreased to avoid instability; however, the source current THD gets reduced. Fig. 6 represents the system frequency response. From this figure, it is concluded that the system is stable and its phase margin is about 90 degree.

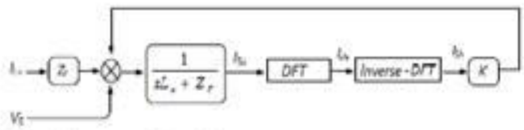

Fig. 3. Block diagram of the whole system.

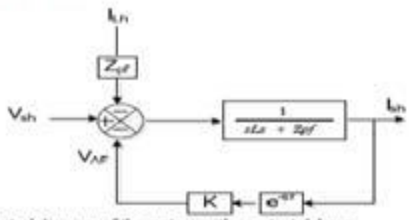

Fig. 4. Control diagram of the system with constant delay τ.

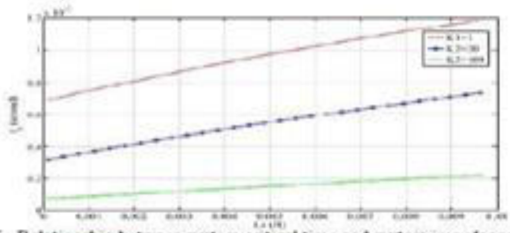
Fig. 5. Relationship between system critical time and system impedance.

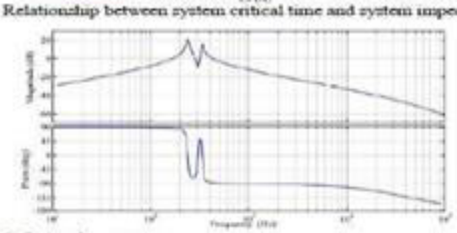
Fig. 6. System frequency response.

IV.FREQUENCY RESPONSE OF THE POWER SYSTEM

Single phase harmonic equivalent circuit of the power system, given in Fig. 1, is explained in Fig. 7. In the figure, the voltage source harmonics are represented as Vsh, and it is in series with the Thevenin impedance (Zs) of the power system.

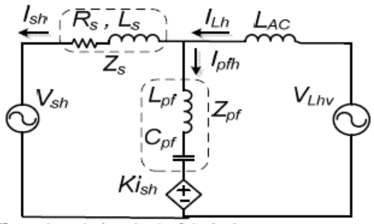

Fig. 7. Harmonic equivalent circuit of single phase system.

Here nonlinear load is a diode rectifier with a resistive capacitive load on its output. This load has typically a voltage source characteristic because an inductor is on rectifier input, and this makes it as a current source type load characteristic. The load is modeled by harmonic voltage VLhv in series with inductor LAC. The series active filter behaves as a damping resistor which is responsible for elimination of resonance between the parallel passive filter and the source impedance. It also prevents allowing of harmonic currents to the power source by experiencing zero impedance at the fundamental frequency and a high resistance K at the power source or load harmonics. So, the series active filter is modeled by a resistor, K, and its output reference voltage as:

$$V_{af} = Ki_{sh}$$

where Ish is the harmonic current flowing from the power source, produced by both the load harmonic current (ILh) and the power source harmonic voltage (VSh). Consequently, from the model shown in Fig. 7, the harmonic current of the power source is calculated as:

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$$I_{sh} = \frac{Z_{pf}}{Z_s + Z_{pf} + K} I_{Lh} + \frac{V_{sh}}{Z_s + Z_{pf} + K}$$

where Zs and Zpf are power source and passive filter equivalent impedance, respectively. Based on above equation, when K is large enough greater than Zs and Zpf, the power source harmonic currents will be equal to zero (ISh=0). In information, in this case the source impedance (Zs) has no effect on the parallel passive filter characteristic, and the power source current harmonics will be reduced . If the power source voltage harmonics (VSh) are not considered, the load current will be separated between the passive filter and the power source; in this case, the ratio between the power source harmonic current and the load harmonic current is:

$$\frac{I_{sh}}{I_{Lh}} = \frac{Z_{pf}}{Z_S + Z_{pf} + K}$$

Fig. 8 represents the frequency response for various values of K. As seen in this figure, when the passive filter is used alone (K=0), then two resonances occur between the parallel passive filter and the power source impedance at around 130 Hz and 240 Hz. Also, when the series active filter is placed along with the passive filter, since the series active filter behaves as damping resistor, so there is no resonance in the system.

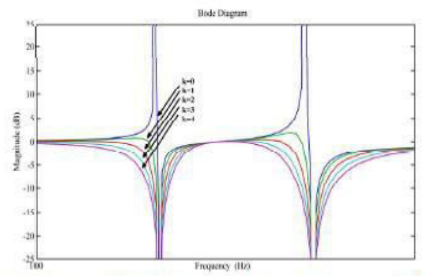


Fig. 8. Frequency response of the hybrid series active filter for different values of K.

V.SIMULATION RESULTS AND OBSERVATION

Harmonic reduction and reactive power compensation by HSAF is publicized in this section through simulation. A HSAF with the procedure offered above is simulated in MATLAB. In this simulation two single tuned passive filters which are tuned to 3rd and 5th harmonics were used with the parameters specified in Table I.Fig. 9 shows the simulation outcome when the active filter is in off-line mode. The power source current THD (iL) without compensation is calculated about 70 %. Also, in passive filter compensation manner, the THD of the power source current (is) reduced from 70% to about 41 %. Still, this THD value has not been less than the recommended value in standards such as IEEE 519-1992 [21] and IEC61000 [22].

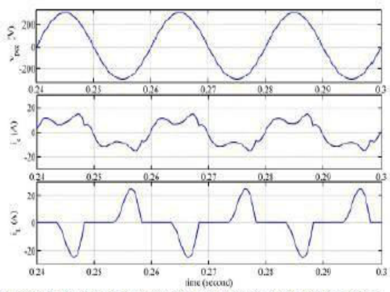
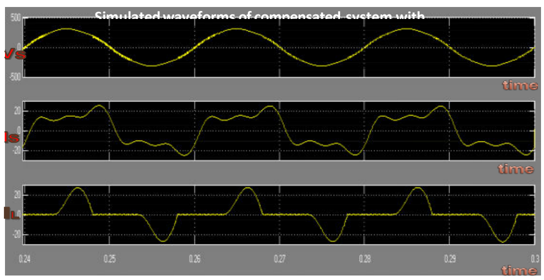


Fig. 9. Simulated waveforms of compensated system with passive filter.



To further reduce the value of the THD, the active filter is placed in the circuit with the dc capacitor voltage of 85V. Fig. 10 shows the simulation results for this case. The THD of the power source current (is) reduced from 41% in off-line active filter mode to about 2.75 % .

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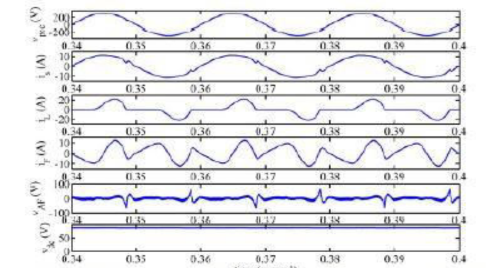
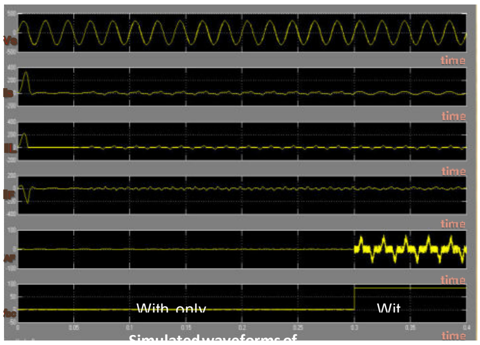


Fig. 10. Simulated waveforms of the compensated system with the hybrid series active filter.



VI.CONCLUSION

This thesis presents HSAF for harmonic reduction and reactive power compensation in a single phase system with a control method as Discrete Fourier Transformation.. This method is applicable in both single and three phase systems. The main advantage of the presented Hybrid series active filter is that its filter's power rating is 10% of the load making it a cost- effective solution for high power applications. The value of the Total harmonic Distortion is around 2.75%. The effectiveness of the present method is simulated by using MATLABn Simulink.

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