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HARMONIC ELIMINATION IN SINGLE PHASE SYSTEMS USING DSP

A. JYOTHI BASU[1] and B. SREE LAXMI[2]

[1] Pursuing M.Tech , S R College of Engineering & Tech, Hanumakonda, Warangal,
jyothibasu202@gmail.com

[2] Asst. Professor, Department of Electronics & Communication Engineering,
Ellenki College of Engg &Tech, Hyderabad.
srilaxmi45@gmail.com

ABSTRACT

In this paper, a fully-digital-controlled hybrid series active filter (HSAF) for harmonic elimination and reactive power compensation in single phase systems is presented. Here we use shunt active filters consisting of voltage-fed pulse width modulated (PWM) inverters using IGBT or GTO. This paper uses a Discrete Fourier transform for single phase active power filters (APF). The HSAF is composed of two single tuned LC filters and a small-rated active filter. The HSAF consists of a series active filter and two parallel single tuned passive filters in series with the active filter. Two passive filters are tuned in dominants harmonic frequencies of 3rd and 5th. One of the key points for proper implementation of an APF is to use a reliable method for current/voltage reference generation. The voltage source harmonics are modelled. Harmonic equivalent circuit of single phase system. Is in series with the Thevenin's impedance (Zs) of the power system. Also, nonlinear load is a diode rectifier by a resistive – capacitive load on its output. Here series active filter behaves as a damping resistor which can eliminate resonance between the parallel passive filter and the source impedance. The main advantage of the presented 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.

Keywords: HSAF, PWM, APF, FFT, LC FILTERS

INTRODUCTION

With the developments of power electronic equipments and nonlinear loads, the power quality has been deteriorating in distribution system. Current harmonics can cause serious harmonic problems in distribution feeders for sensitive consumers. Some technology options have been reported in order to solve power quality issues. Initially, lossless passive filters have been used to mitigate harmonics and compensate reactive power in nonlinear loads. However, passive filters have the demerits of fixed compensation, large size and resonance with the supply system.

POWER QUALITY PROBLEMS: The purpose of this article, we shall define power quality problems as any power problem that results in failure or miss operation of customer equipment, manifests itself as an economic burden to the user, or produces negative impacts on the environment.' When applied to the container crane industry, the power issues which degrade power quality include: 1).Power Factor 2) Harmonic Distortion 3) Voltage Transients 4). Voltage Sags or Dips 5)Voltage Swells

The power quality can be improved through by Power factor correction, Harmonic filtering, Special line notch filtering, transient voltage surge suppression, Proper earthing systems.

APPLICATIONS OF POWER QUALITY: Power quality in the container terminal environment impacts the economics of the terminal operation, affects reliability of the terminal equipment, and affects other consumers served by the same utility service. Each of these concerns is explored in the following points 1. Economic Impact: Power Factor Penalties, System Losses, Power Service Initial Capital Investments 2. Equipment Reliability 3. Power System Adequacy 4. Environment

HARMONICS

The typical definition for a harmonic is “a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.” [1]. Some references refer to “clean” or “pure” power as those without any harmonics. But such clean waveforms typically only exist in a laboratory. Electrical generators try to produce electric power where the voltage waveform has only one frequency associated with it, the fundamental frequency.

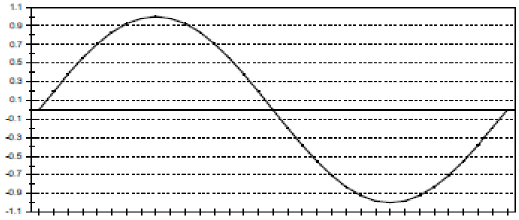


Fig 1.1 Sine wave

The frequency of the harmonics is different, depending on the fundamental frequency. For example, the 2nd harmonic on a 60 Hz system is 2*60 or 120 Hz. At 50Hz, the second harmonic is 2* 50 or 100Hz. 300Hz is the 5th harmonic in a 60 Hz system, or the 6th harmonic in a 50 Hz system. Figure shows how a signal with two harmonics would appear on an oscilloscope-type display, which some power quality analyzers provide.

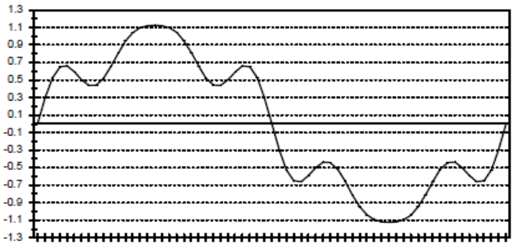


Fig. 1.2 Fundamental with two harmonics

PROBEM OF HARMONICS: The presence of harmonics does not mean that the factory or office cannot run properly. Like other power quality phenomena, it depends on the “stiffness” of the power distribution system and the susceptibility of the equipment. As shown below, there are a number of different types of equipment that can have mis operations or failures due to high harmonic voltage and/or current levels. In addition, one factory may be the source of high harmonics but able to run properly. This harmonic pollution is often carried back onto the electric utility distribution system, and may effect facilities on the same system which are more susceptible.

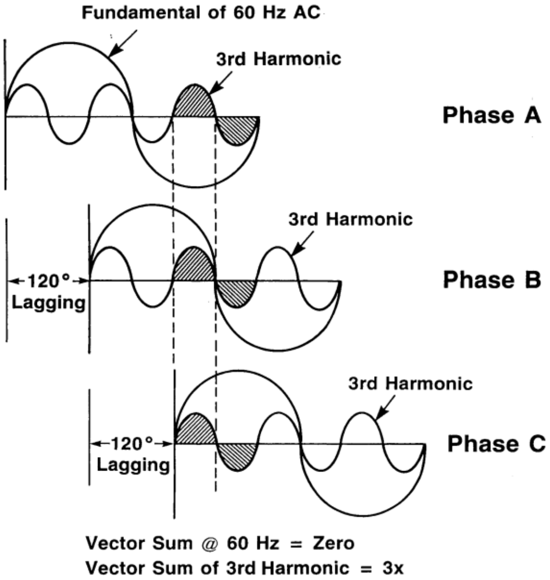
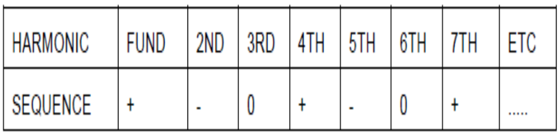


Fig. 1.3 Additive Third Harmonics

1. Incorrect reading meters, including induction disc W-hr meters and averaging type current meters. 2. Reduced true PF, where PF= Watts/VA. 3. Overheated transformers, especially delta windings where triplen harmonics generated on the load side of a delta-wye transformer will circulate in the primary side. Some type of losses go up as the square of harmonic value (such as skin effect and eddy current losses). This is also true for solenoid coils and lighting ballasts. 4. Zero, negative sequence voltages on motors and generators. In a balanced system, voltage harmonics can either be positive (fundamental, 4th, 7th,...), negative (2nd, 5th, 8th...) or zero (3rd, 6th, 9th,...) sequencing values. This means that the voltage at that particular frequency tries to rotate the motor forward, backward, or neither (just heats up the motor), respectively. There is also heating from increased losses as in a transformer.

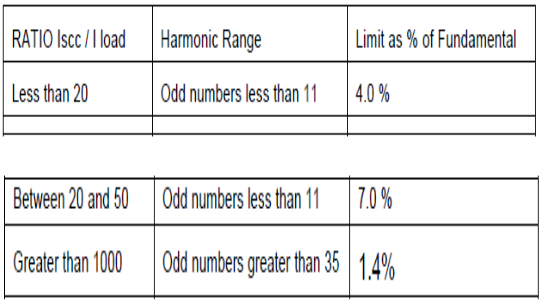


HARMONIC	FUND	2ND	3RD	4TH	5TH	6TH	7TH	ETC
SEQUENCE	+	-	0	+	-	0	+	.....

Table 1. Harmonic Sequencing Values in Balanced Systems

5. Nuisance operation of protective devices, including false tripping of relays and failure of a UPS to transfer properly, especially if controls incorporate zero-crossing sensing circuits. 6. Bearing failure from shaft currents through un insulated bearings of electric motors. 7. Blown-fuses on PF correction caps, due to high voltage and currents from resonance with line impedance.

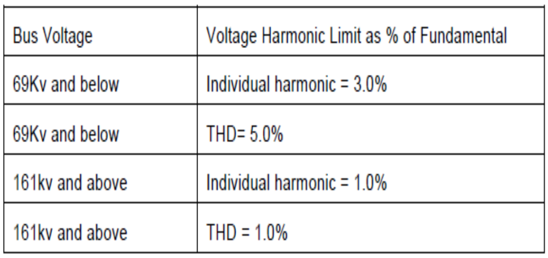
8. Mis-operation or failure of electronic equipment
9. If there are voltage sub harmonics in the range of 1-30Hz, the effect on lighting is called flicker. This is especially true at 8.8Hz, where the human eye is most sensitive, and just 0.5% variation in the voltage is noticeable with some types of lighting. [2]. To determine what is normal or acceptable levels, a number of standards have been developed by various organizations. ANSI/IEEE C57.110 Recommended Practice for Establishing Transformer Compatibility When Supplying No sinusoidal Load Currents is a useful document for determining how much a transformer should be derated from its nameplate rating when operating in the presence of harmonics. There are two parameters typically used, called K-factor and TDF (transformer dereading factor). Some power quality harmonic monitors will automatically calculate these values. IEEE 519-1992 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems provides guidelines from determining what acceptable limits are. The harmonic limits for current depend on the ratio of Short Circuit Current (SCC) at PCC (or how stiff it is) to average Load Current of maximum demand over 1 year, as illustrated in Table 2. Note how the limit decreases at the higher harmonic values, and increases with larger ratios.



RATIO Iscc / I load	Harmonic Range	Limit as % of Fundamental
Less than 20	Odd numbers less than 11	4.0 %
Between 20 and 50	Odd numbers less than 11	7.0 %
Greater than 1000	Odd numbers greater than 35	1.4%

Table 2. Current Harmonic Limits as per IEEE 519-1992

For voltage harmonics, the voltage level of the system is used to determine the limits, as shown in Table 6. At the higher voltages, more customers will be effective, hence, the lower limits.



Bus Voltage	Voltage Harmonic Limit as % of Fundamental
69Kv and below	Individual harmonic = 3.0%
69Kv and below	THD= 5.0%
161kv and above	Individual harmonic = 1.0%
161kv and above	THD = 1.0%

Table 4. Voltage Harmonic Limits as per IEEE 519-1992.

The European Community has also developed susceptibility and emission limits for\ harmonics. Formerly known as the 555-2 standard for appliances of less than 16 A, a more encompassing set of standards under IEC 1000-4-7 are now in effect.

TOTAL HARMONIC DISTORTION:

Harmonic problems are almost always introduced by the consumers' equipment and installation practices. Harmonic distortion is caused by the high use of non-linear load equipment such as computer power supplies, electronic ballasts, compact fluorescent lamps and variable speed drives etc, which create high current flow with harmonic frequency components. The limiting rating for most electrical circuit elements is determined by the amount of heat that can be dissipated to avoid overheating of bus bars, circuit breakers, neutral conductors, transformer windings or generator alternators.

FILTER DESIGN

Which perform signal processing functions, specifically to remove unwanted frequency components from the signal, to enhance wanted ones, or both. Electronic filters can be: passive or active analog or digital , high-pass, low-pass, band pass, band-reject (band reject; notch), or all-pass., discrete-time (sampled) or continuous-time, linear or non-linear, infinite impulse response (IIR type) or finite impulse response (FIR type).

Filter Design:

Constant active power algorithm

The instantaneous and average powers of the load are calculated. The active power component of the system is controlled to keep the instantaneous real power constant, while maintaining the imaginary power to zero. This technique performs fairly well under ordinary conditions. However, the performance deteriorates when the supply is contaminated.

Constant power factor algorithm

This technique forces the instantaneous current signal to track the voltage-reference waveform. This implies that the power factor is fixed to unity and the system would only be suitable for the combined system of VAR and current-harmonic compensation.

Synchronous flux detection algorithm

This technique applies Park transformations to transfer the system into synchronously rotating direct, quadrature and zero-sequence frames of reference. However, it applies the transformation on the flux linkage of the filter inductance, which is then controlled using the output voltages and currents in separate integral loops. The presence of these integral loops incorporates time delays, which depend on the frequency response of the special feed forward and feedback integrators.

Frequency domain approaches

The frequency-domain methods are mainly identified with Fourier analysis, rearranged in such a manner that this provides the result as fast as possible with a reduced number of calculations, to allow a real-time implementation in DSP’s.

Once the Fourier transform is taken, the APF converter-switching function is computed to produce the distortion canceling output. With this strategy the inverter switching frequency must be more than twice the highest compensating harmonic frequency. This strategy has a poorer dynamic response and it not as widely used.

Conventional Fourier and FFT algorithms

Using the Fast Fourier Transform (FFT), the harmonic current can be reconstructed by eliminating the fundamental component from the transformed current signal and then the inverse transform is applied to obtain a time-domain signal. The main disadvantage of this system is the accompanying time delay. This technique needs to take samples of one complete cycle (or an integral number of cycles) to generate the Fourier coefficients and it is therefore suitable for slowly varying load conditions.

Other algorithms

There are numerous optimization and estimation techniques, and all the utilities and libraries for estimation can be used to perform this task. However some new methods arise, such as the neural network and adaptive-estimation techniques which are fairly accurate and have, of course, much better response. Unfortunately, presently available control hardware is not suitable for implementation of these techniques.

IMPLEMENTATION OF HARMONIC ELIMINATION USING A HYBRID SERIES ACTIVE FILTER (HSAF)

The active filters can be classified into pure active filters and hybrid active filters in terms of their circuit configuration. Most pure active filters as their power circuit can use either a voltage-source pulse width-modulated (PWM) converter equipped with a dc capacitor or a current-source PWM converter equipped with a dc inductor. At present, the voltage source converter is more favorable than the current-source one in terms of cost, physical size, and efficiency. Hybrid active filters consist of single or multiple voltage-source PWM converters and passive components such as capacitors, inductors, and/or resistors. The hybrid filters are more attractive in harmonic filtering than the pure filters from both viability and economical points of view, particularly for high-power applications. However, single-phase active filters would attract much less attention than three-phase active filters because single phase versions are limited to low-power applications except for electric traction or rolling stock.

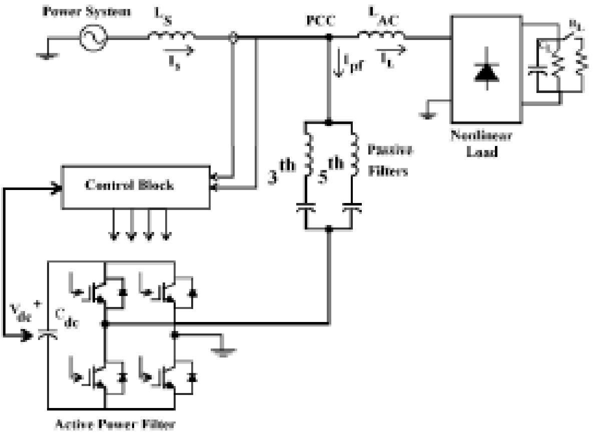


Fig.4.1. System configuration

Fig. 4.1 shows the configuration of the HSAF and nonlinear load proposed in this paper and, its parameters are given in Table I. The HSAF consists of a series active filter and two parallel single tuned passive filters in series with the active filter. Two passive filters are tuned in dominants harmonic frequencies of 3rd and 5th. The effectiveness of the proposed method in harmonic elimination and reactive power compensation is shown using HSAF for a nonlinear load. In the following sections, the control method, the design process and simulation results are given.

COMPENSATION STRATEGY

One of the key points for proper implementation of an APF is to use a reliable method for current/voltage reference generation. Currently, there is a large variety of practical implementation supported by different theories (either in time or frequency domain). The control method should 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:

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

$$x_{k1} = \frac{1}{N} X_1 e^{\frac{-j2\pi k}{N}} \tag{2}$$

Where (1) is DFT and (2) is inverse DFT. After extracting the fundamental component, it is subtracted from source current to extract harmonic components as:

$$i_{Sh} = i_S - i_{S1} \tag{3}$$

Fig. 4.2 shows the control circuit. A method was proposed by Akagi to control the dc voltage capacitor. Based on this method, if active filter is along the passive filter, an extra voltage reference should be added to q component.

As seen in this figure, a component with 90 degree lead the load terminal voltage is added to reference voltage in order to control the dc link voltage capacitor.

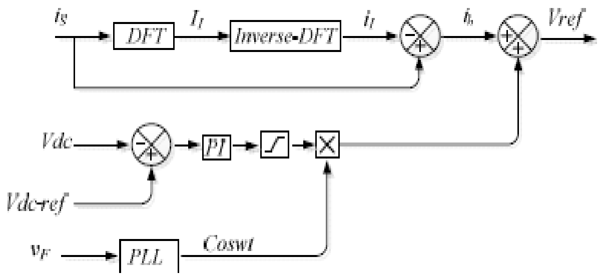


Fig. 4.2. Control circuit of hybrid series active filter

SYSTEM STABILITY ANALYSIS

Fig. 4.3 shows whole system block diagram. Active filter shows zero impedance against fundamental component of the source current while it shows high impedance against harmonics. In Fig.4.3, analog to digital converters in control circuit give rise to some delays in system. Also, it takes some time to extract harmonic components by the microcontroller. Assuming all the delays in the system as τ, Fig.4.4 shows the system control diagram. So, the open-loop transfer function will be as:

$$G(s) = \frac{K}{sL + Z_F} e^{-s\tau} \tag{4}$$

Eqs. (4) Represents that if τ is zero, the system will always be stable. However, the existence of noise is unavoidable. Fig. 5 shows the relationship between system critical time (τ) and system impedance in different values of K. As seen in this figure, as K increases, the system critical time decreases to avoid instability; however, the source current THD decreases. Fig. 4.6 shows the system frequency response. As this figure shows, the system is stable and its phase margin is about 90 degree.

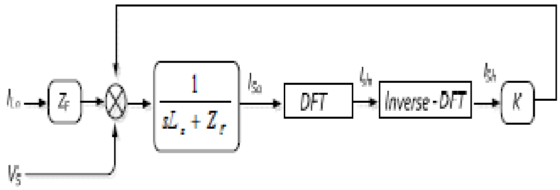


Fig. 4.3. Block diagram of the whole system

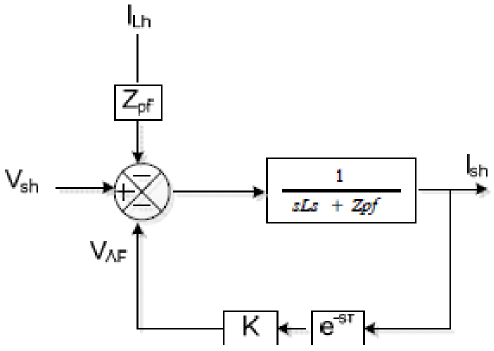


Fig. 4.4. Control diagram of the system with constant delay τ

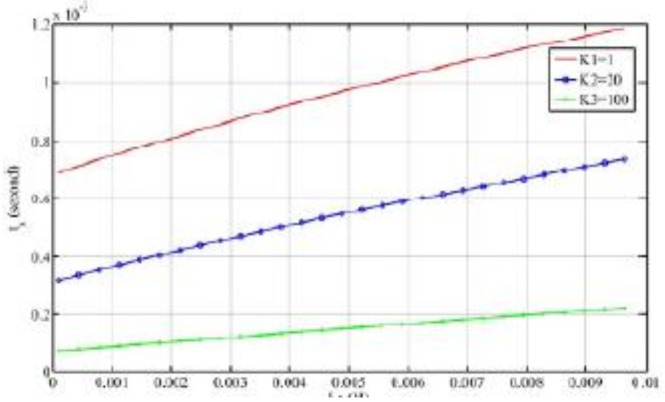


Fig. 4.5. Relationship between system critical time and system impedance

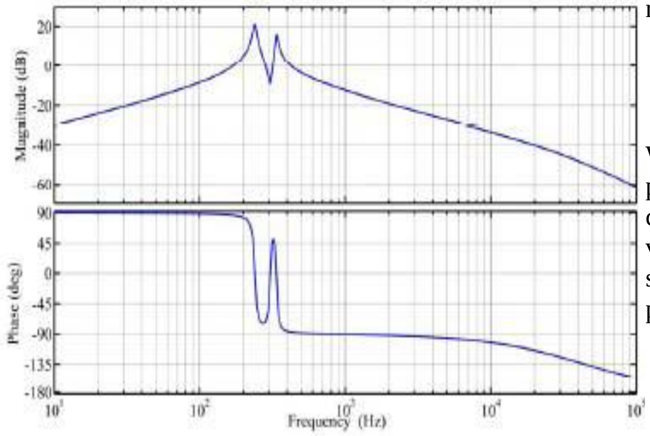


Fig. 4.6. System frequency response

FREQUENCY CHARACTERISTIC OF THE SYSTEM

Single phase harmonic equivalent circuit of the power system, shown in Fig. 4.1, is demonstrated in Fig. 4.7. In this figure, the voltage source harmonics are modeled by Vsh, and it is in series with the Thevenin impedance (Zs) of the power system. Also, nonlinear load is a diode rectifier by a resistive – capacitive load on its output. This load has usually 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 can eliminate resonance between the parallel passive filter and the source impedance. It also prevents flowing of harmonic currents to the power source by presenting zero impedance at the fundamental frequency and a high resistance K at the power source or load harmonics.

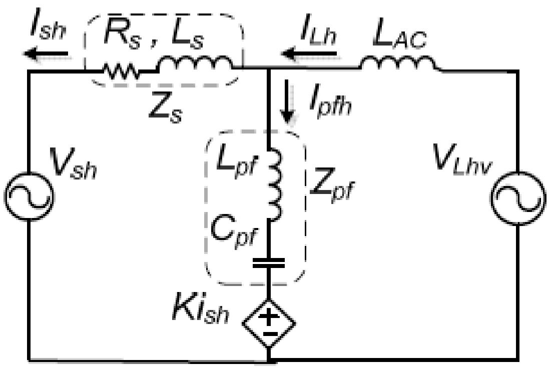


Fig. 4.7. Harmonic equivalent circuit of single phase system

So, the series active filter can be modeled by a resistor, K, and its output reference voltage as:

$$V_{af} = Ki_{sh} \tag{5}$$

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. 4.7, the harmonic current of the power source is calculated as:

$$I_{sh} = \frac{Z_{pf}}{Z_s + Z_{pf} + K} I_{Lh} + \frac{V_{sh}}{Z_s + Z_{pf} + K} \tag{6}$$

Where Zs and Zpf are power source and passive filter equivalent impedance, respectively

Based on (6), when K is large enough greater than Zs and Zpf, the power source harmonic currents will be equal to zero (ISh=0). In fact, in this case the source impedance (Zs) has no impact on the parallel passive filter characteristic, and the power source current harmonics will completely be eliminated. If the power source voltage harmonics (VSh) is not considered, the load current will be divided 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:

$$\frac{I_{sh}}{I_{Lh}} = \frac{Z_{pf}}{Z_S + Z_{pf} + K} \tag{7}$$

Fig. 4.8 shows the frequency response for different values of K. As seen in this figure, when the passive filter is used alone (K=0), two resonances occur between the parallel passive filter and the power source impedance at about 130 Hz and 240 Hz. Also, when the series active filter is used along with the pass ive filter, since the series active filter behaves as a damping resistor there is no resonance in the system.

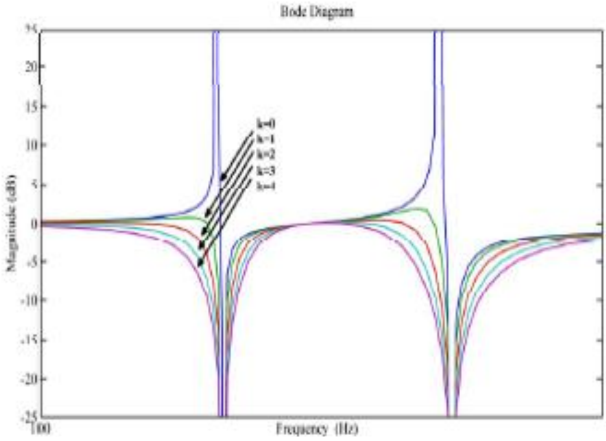


Fig. 4.8. Frequency response of the hybrid series active filter for different values of K

RESULTS

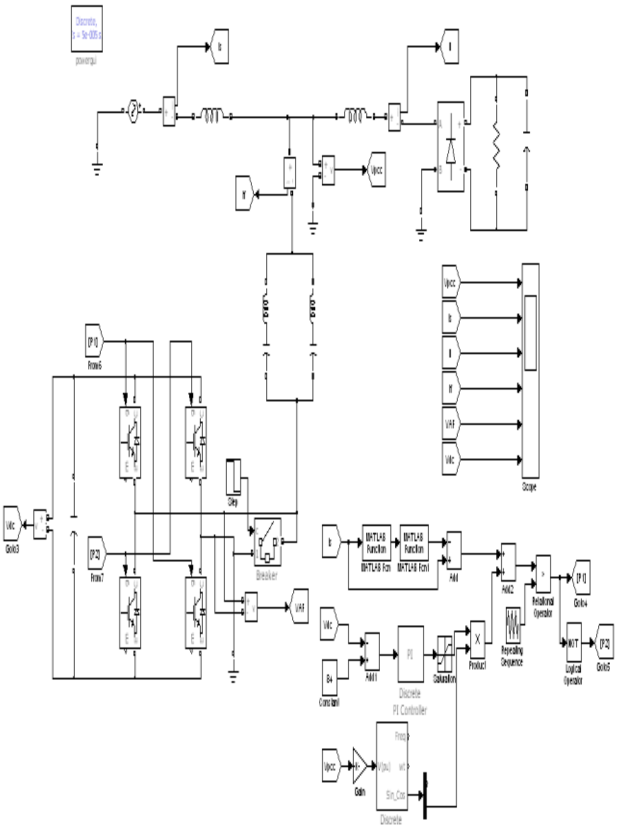


Fig 5.1 Simulink model of Hybrid Series Active Filter (HSAF)

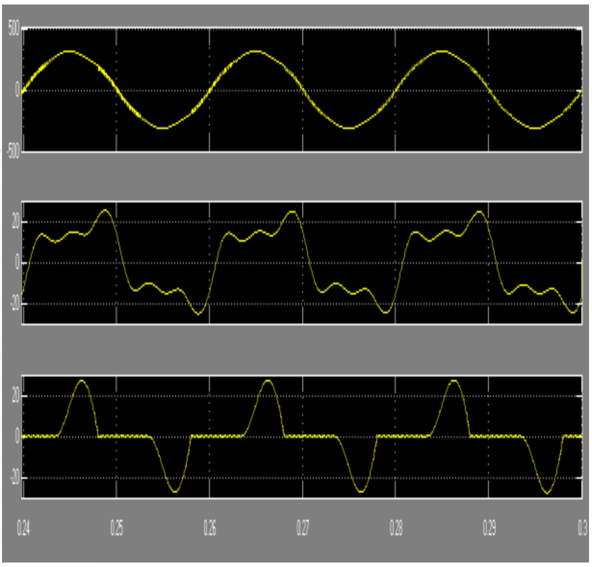


Fig. 5.2 Simulated waveforms of compensated system with passive filter.

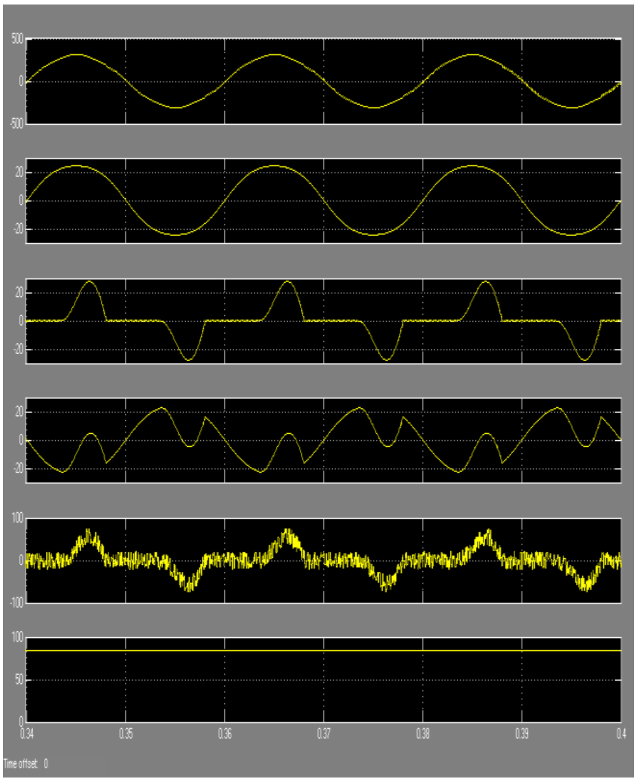


Fig. 5.3 Simulated waveforms of the compensated system with the hybrid series active filter.

CONCLUSION

This paper presents a fully digitally controlled HSAF for harmonic elimination and reactive power compensation in a single phase system with a control method for series active filter. This method is applicable in both single and three phase systems.

The main advantage of the presented 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 performance of the proposed control method is simulated for a HSAF.

The simulation results show the effectiveness of the presented method. Also, to investigate the effectiveness of this method reality, a laboratory prototype 220 V– 2.2 kW HSAF is implemented.

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