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Compensation of Harmonics Power by using Shunt Active Filter

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Abstract* — The main application of power electronic equipments is to increases the results of poor power quality of system. Load harmonics current reduces the power quality supplied by power system. Due to current harmonics has become a major problem for the utilities at distribution levels. The non-sinusoidal voltage and current adversely affects on the performance of various electrical equipments connected in the system. Thus, it is necessary to eliminate these harmonics present in voltage and current in various parts of the power system. This paper presents a three phase shunt active filter connect at point of common coupling capable of reducing the total harmonics distortion in Power System. In order to improve the power factor, compensation of total harmonics distortion drawn from a three phase diode bridge rectifier load. Synchronous d-q reference frame is used for generation of reference current for the shunt active filter. The Phase Locked Loop is used for synchronization and provide phase of the positive sequence of the system voltage. Hysteresis current control technique is used as pulse width modulation technique for the switches of voltage source inverter. Simulations were carried out using MATLAB Simulink software to validate the performance of the shunt active filter connected to a three phase diode bridge rectifier. The results of simulation study presented in this paper are found quite satisfactory to eliminate harmonics components from utility current. The shunt active filter is found effective to meet IEEE 519 standard recommendations on harmonics levels.

Keywords- Shunt Active Filter, Total Harmonic distortion (THD), Phase Locked Loop(PLL), Pulse Width Modulation(PWM), Voltage Source Inverter (VSI)

I. INTRODUCTION

The variation of voltage, current and power from it's ideal waveform is called as power quality problem in power system. In recent years, the developments of power electronics have great advantage in energy conversion and utilization. Power electronics equipment draws distorted current from the system. As the current distortion is conducted through transmission line, it creates voltage distortion in various parts of the power system. Voltage distortion increases because of current distortion has become a major problem for the utilities at distribution and transmission levels. Line losses and losses in electrical equipments connected in the transmission system are increased due to the high harmonic or distortion current flowing through system. Harmonics current producing loads cause additional losses in power cables, transformers and capacitors. Harmonics voltage is induced because of them at supply transformer. Due to this harmonics distortion sensitive loads may be disturbed or damaged.

By considering the effects of harmonics in various equipments in power system, it is necessary to eliminate these harmonics. Traditionally, passive LC filter, capacitor bank and TCR are used to filter the harmonics and compensate the reactive current components due to non-linear loads. They are simple control but very complex under resonant conditions. When the supply voltage waveforms are non sinusoidal, the problems with passive filters are more pronounced due to the possibility of filter overloading and resonance. The conventional filters have some disadvantages such as the fixed compensation, large size and resonance. To overcome these problems active filters are introduced. Active filters are basically categorized based on series or shunt and unified power quality conditioners (UPQC) and Hybrid filters.

This paper deals with a implementation of shunt active filter using shunt active filter. This paper based on the three phase d-q theory based control with three phases phase lock loop (PLL) of SAF. The basic structure of synchronous reference frame methods consists of direct d-q and inverse d-q^{-1} Park transformations, which allow the evaluation of a specific harmonic component of the load current and a low-pass filtering stage. The basic principle of shunt active filter is explained in section II, d-q synchronous reference frame theory of generation of compensating current is given in Section III, In section IV Hysteresis current controller loop for voltage source inverter (VSI) is given, simulation results of SAF is evaluated in section V and conclusions are drawn in section VI.

II. BASIC PRINCIPLE OF SHUNT ACTIVE FILTERS

A shunt active filter connected to a simple power system is shown in Fig. 1. Assume that non-linear loads are connected at point of common coupling (PCC). The system comprises balanced three phase voltage source (V_a , V_b , V_c) feeding a three phase diode bridge rectifier with resistive load. The SAF is connected to three phase through inductor L. Converter employed for SAF is MOSFET based converter , it is a current controlled voltage source inverter which is connected in parallel with load. This inverter injects the reference compensating current into system to compensate harmonics components of load current. The quality and performance of SAF is depending on technique used to harmonic detection and current controller topologies. DC storage capacitor is used as input of VSI DC link voltage. This DC link voltage is maintain constant by adding external loop in generation of reference compensating current topology. VSI firing pulses are generated by current control topologies.

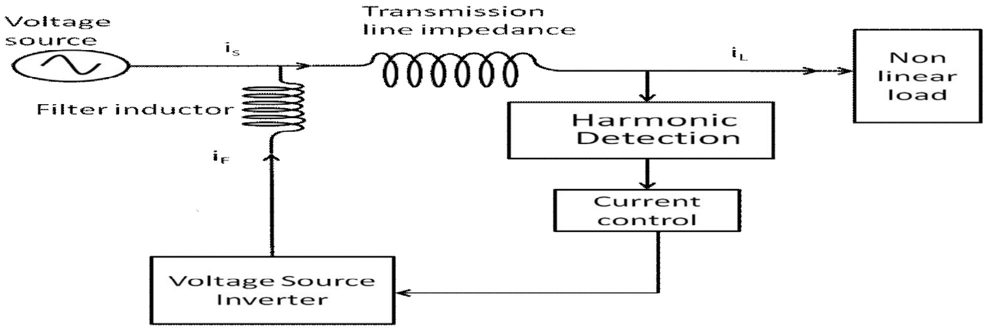


Fig. 1 Basic block diagram of shunt active filter

SAF is provided compensation for harmonic current drawn by load, so that input source supply only fundamental component of load current.

III. SYNCHRONUS D-Q REFRENCE FRAME THEORY

The three-phase load currents (i_{LA}, i_{LB}, and i_{LC}) are transformed into the instantaneous active (i_d) and reactive (i_q) components using a rotating frame synchronous with the positive sequence of the system voltage as given below:

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin\omega_{st} & \sin\omega_{st} - \frac{2\pi}{3} & \sin\omega_{st} + \frac{2\pi}{3} \\ \cos\omega_{st} & \cos\omega_{st} - \frac{2\pi}{3} & \cos\omega_{st} + \frac{2\pi}{3} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix} \ldots(1)$$

Where, ω_{st} is the phase of the positive sequence of the system voltage and it is provided by a phase-locked loop(PLL). The PLL generates sin ω_{st} and cos ω_{st} functions at the fundamental frequency, synchronized with the fundamental component of the voltage. The active and reactive currents can also be decomposed in their dc and ac values as follows:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} i_{d_{dc}} \\ i_{q_{dc}} \end{bmatrix} + \begin{bmatrix} i_{d_{ac}} \\ i_{q_{ac}} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

id_{dc} and iq_{dc} are the mean value component supply by the source and the id_{ac} and iq_{ac} are the harmonics component of load current.

$$\begin{bmatrix} i_{d_{ac}} \\ i_{q_{ac}} \end{bmatrix} = \begin{bmatrix} i_d \\ i_q \end{bmatrix} - \begin{bmatrix} i_{d_{dc}} \\ i_{q_{dc}} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Then, the reference currents in the *abc* frame are as per follow equation 8,

$$\begin{bmatrix} i_{CA} \\ i_{CB} \\ i_{CC} \end{bmatrix} = \begin{bmatrix} \sin(\omega_{st}) & \cos(\omega_{st}) \\ \sin\left(\omega_{st} - \frac{2\pi}{3}\right) & \cos\left(\omega_{st} - \frac{2\pi}{3}\right) \\ \sin\left(\omega_{st} + \frac{2\pi}{3}\right) & \cos\left(\omega_{st} + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} \ldots\ldots(4)$$

In synchronous d-q reference frame extraction of fundamental and harmonics component of current and voltage are easy. This theory is applicable to single phase with neutral conductor and three phase with or without neutral conductor. It has more accurate results with steady state and transient condition [1, 7, 8]. This synchronous frame theory is used in SAF simulation.

IV. HYSTERESIS CURRENT CONTROL TECHNIQUE

The hysteresis band current controller for active power filter can be carried out to generate firing pulse of the inverter. There are various current control methods proposed for such active power filter configurations, but in terms of quick current controllability and easy implementation hysteresis current control method has the highest rate among other current control methods. Hysteresis band current controller has properties like robustness, excellent dynamics and fastest control with minimum hardware. Each current controller directly generates the switching signal of the three phases. Pulse generated for switch using hysteresis technique is shown in the Fig.2.

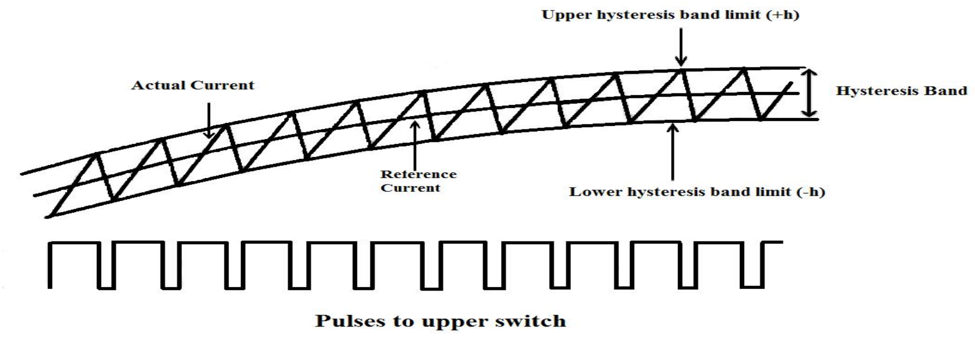


Fig.2. Hysteresis current PWM control operation waveform.

In the case of positive input current, if the error current between the reference current and the actual source current exceeds the upper hysteresis band limit (+h), the upper switch of the inverter arm is turned OFF and the lower switch is turned ON. The current ramping up and down between two limits is shown in Fig.2. Similarly the error current between the reference current and the actual current is less than the lower band limit (-h) the upper switch is turned on and lower switch is turned off. Its complement will be given to lower switch. MATLAB simulation implementation of SAF has been done using hysteresis control technique.

V. SIMULATION RESULTS

A MATLAB simulation is done to implement shunt active filter using synchronous d-q theory. A sinusoidal three phase supply is assumed and details are given in Table 1. A 3Φ diode Rectifier with 5 Ω resistor is used as a non-linear load.

Fig. 2. shows the simple power system model of diode bridge rectifier model using MATLAB.

Table. 1 Parameters of power system

Parameter	Values
Supply voltage (V_{L-L})	440V
Frequency	50Hz
Load (Non linear)	62.4KVA
Load Resister(R)	5Ω

The waveforms of source voltage (v_{sa}) and current (i_{sa})of phase a are given in Fig. 3. From the figure it is clear that though the supply voltage is sinusoidal the load current is non-sinusoidal. Due to the distortion in current the total harmonic distortion (THD) in current will be more which will affect the power factor of the system. The measured power factor and THD of the circuit is 0.95 and 29.51%. Before the compensation the supply current i_S is same as the load current i_L. Table 2, shows the simulation results of before compensation.

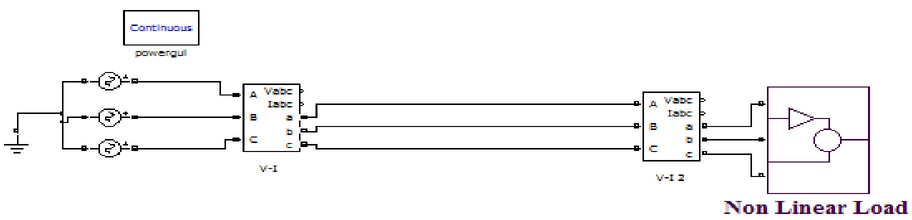


Fig.2. Power system model of non linear load

To make power factor unity the current should be sinusoidal and in phase with the supply voltage. From the waveforms in Fig. 3, it is clear that the fundamental component of current is in phase with the voltage. Hence the power factor can be improved by shaping the supply current to a sinusoidal one using shunt active filter.

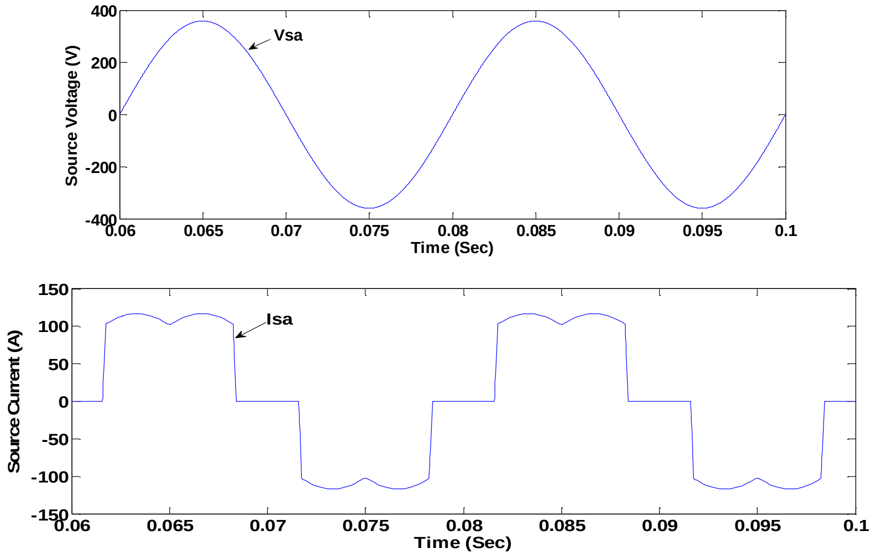


Fig.3. Waveforms of source voltage V_{sa} and source current i_{sa}.

Table. 2 Simulation result of before compensation

P_L (kW)	V_{Lrms} (V)	I_{Lrms} (A)	THD (%)	$P.F._S$
66.45	254	87.23	29.51	0.95

Table shows that power factor is 0.95. Harmonics spectrum of load current is shown in Fig.4 in which 5th, 7th,11th, 13th number of harmonics are present. The measured THD in load current is 29.51%.

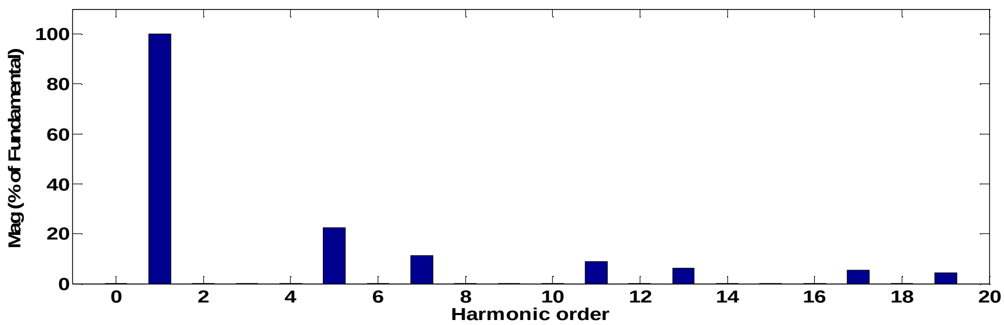


Fig.4. Harmonics Spectrum of load Current i_{la} before compensation

The complete MATLAB model is shown in Fig.5. The generation of compensating current injected by the inverter is calculated using d-q theory. Three phase PLL block is used for getting ω_{st}. Load current is sensed using 3Φ current measurement block and connected to d-q frame. Hysteresis control technique is used for generation of pulses to the inverter switches. For hysteresis control actual output of the inverter is also sensed and connected to d-q frame. Hysteresis control is implemented by compensating these two current and pluses are given to each switch. The reference compensating current and the actual compensating current injected by the current controlled inverter is shown in Fig. 6. It is clear that both the current magnitude and shape is the same.

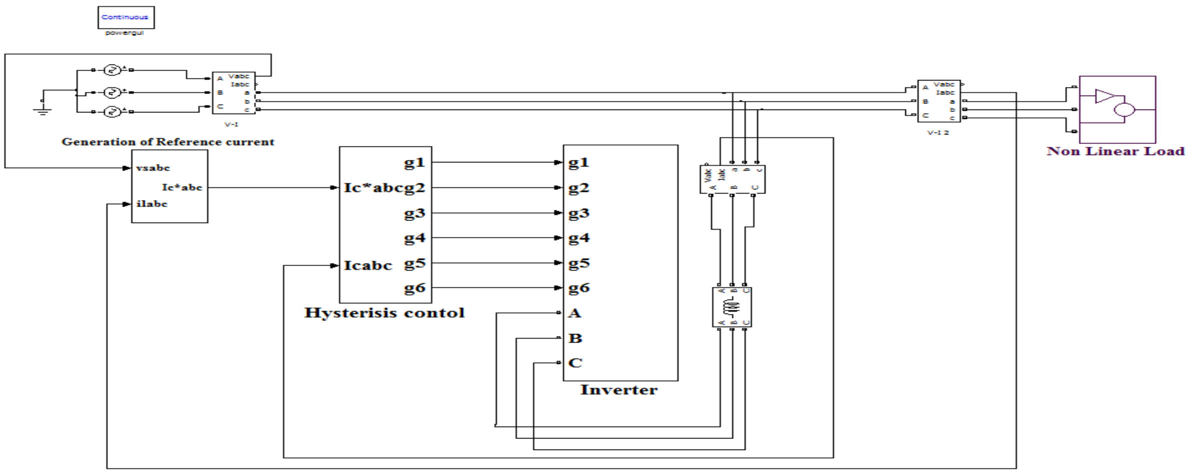


Fig. 5. Model of shunt active filter in Simulation.

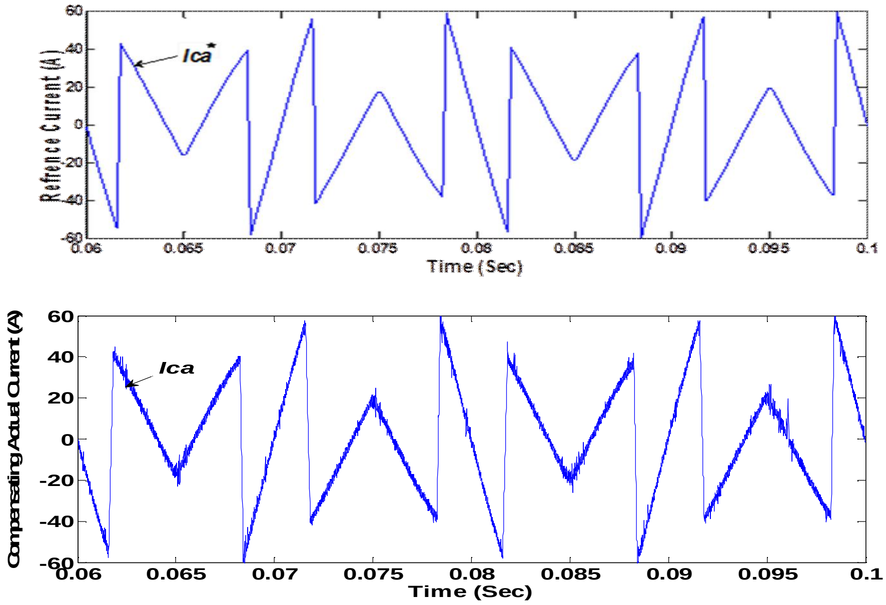
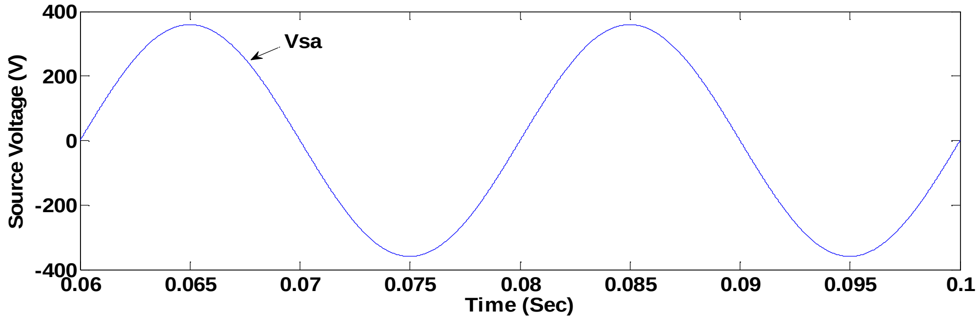


Fig.6. Waveform of phase a reference and actual compensating current i_{Ca}^{*} and i_{Ca}.

Fig.7. shows the source voltage, source current and load current of phase a after compensation. In that we can see after the harmonics compensation the source current become a sinusoidal.



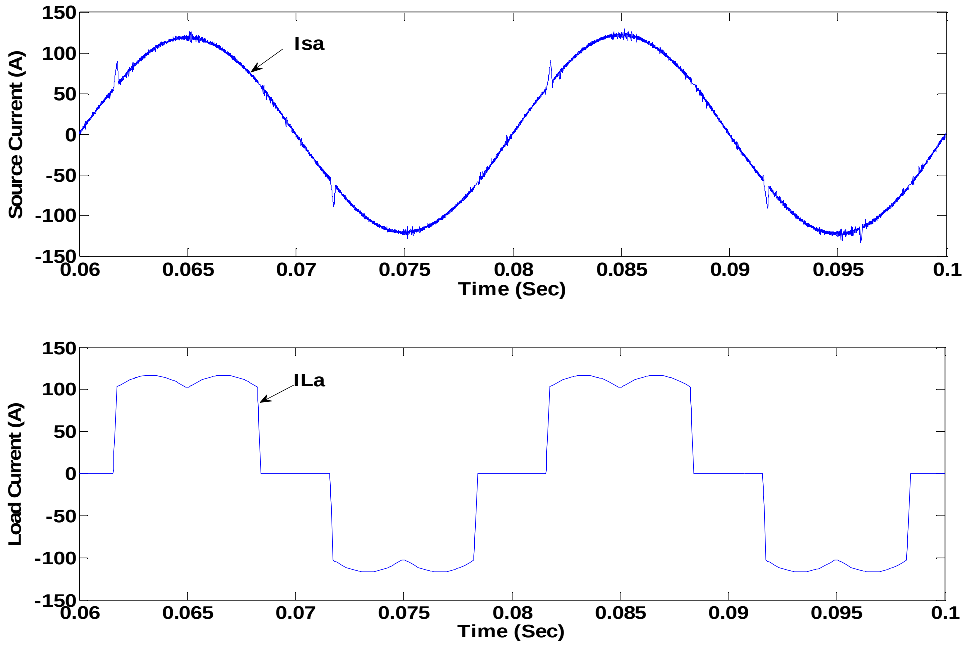


Fig.7. Waveform of v_{Sa}, i_{Sa} and i_{La} after compensation.

Table No. 3. Simulation result of after compensation

i_{Crms} (A)	i_{Srns} (A)	Q_C (kVAR)	THD (%)	P.F.$_S$
3.20	84.04	4.22	3.18	0.99

From the Table 3, we can see Power factor of the supply side is increased from 0.95 to 0.99 and the supply current is reduced from 87.23 to 84.04 Amp. Harmonics spectrum of source current is shown in Fig.8. in which fundamental component is present and remaining 5th, 7th,11th, 13th number of harmonics components are minimizes.

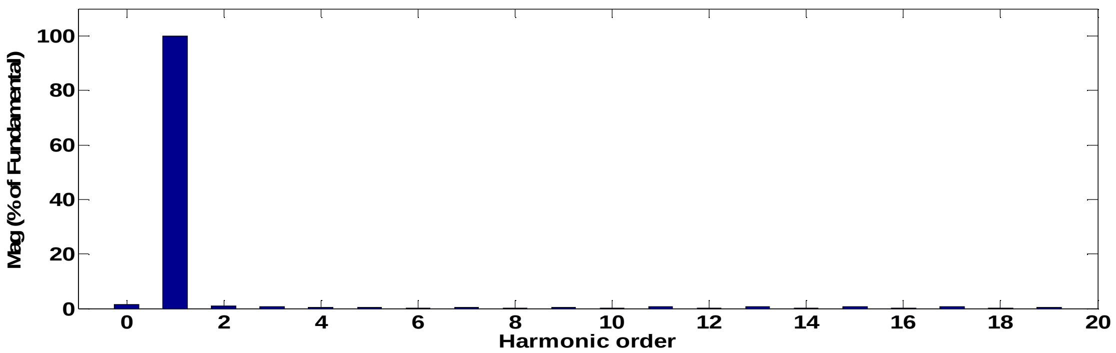


Fig.8. Harmonics Spectrum of source Current i_{sa} after compensation

THD of system reduced from 29.51% to 3.18 % as per the IEEE standard 519 limit.

VI. CONCLUSION

A MATLAB simulation for implementation of shunt active filter is presented. The pulses to the current controlled voltage source inverter which acts as shunt active filter is generated using a synchronous d-q reference frame control technique with hysteresis current control loop. Result shows power factor is improved nearer to unity. Source current THD reduces as per the recommended harmonics standards IEEE 519.

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