

Motor side active power filter for induction motor

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ABSTRACT

Power quality is an important aspect in electrical distribution and utilization systems. Variable frequency drive (VFD) controlled induction motors are widely used in industries. The output current of VFD which is nonsinusoidal is given to the induction motor. This paper proposes a motor side active power filter (MSAPF) so as to provide a pure sinusoidal current to the induction motor. An evaluation of two control strategies has been discussed in this paper *i.e.* synchronous reference frame (SRF) theory and Instantaneous reactive power theory (IRPT) in the generation of the reference signal. These techniques are simulated in MATLAB/Simulink environment. These simulations demonstrate the reduction in total harmonic distortion (THD) in the motor current with active filter connected to the motor side.

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1. INTRODUCTION

In recent days, power quality is one of the main concerns in electric power system. Due to nonlinear loads present in the system, such as static power converters, arc furnaces etc., it results in a variety of undesirable phenomena such as harmonic contamination, increased reactive power demand and power system voltage fluctuations. Among these, harmonic contamination has become a major concern due to its effects on sensitive loads and on the power distribution system. The presence of harmonic components tends to increase power system losses which results in excessive heating of electric machines, cause electromagnetic interference with communication lines that shares common rights-of-way with power lines and generate noise on regulating & control circuits, thereby causing erroneous operation of such equipment. Due to these reasons, Harmonic filters have entered the picture to improve the power quality of the system by reducing harmonic distortion [1-3]. There are two types of harmonic filters *i.e.* passive filter and active filter. The passive filters have the ease of design. However, active filters have various other advantages such as adaptability and better output [4].

Present day, active filters are commonly used to suppress harmonics in the electric power system [5]. Active shunt filters in the network is generally used to make the source current sinusoidal when a nonlinear and unbalanced load is connected to the utility [6]. Studies have been performed on Active filter on the network side using different controllers. A unique topology for a 3-phase active filter is reported in [7]. Controllers that are used in network side filter are fuzzy logic [8], field programmable gate array (FPGA) [9], artificial neural network (ANN) [10], adaptive filtering [11-13] etc. In all these methods, the source current is made sinusoidal which was distorted due to nonlinear and unbalanced loads. Many control strategies have been used to generate the reference current [14-16]. Induction motors (IMs) are widely used in industries. Variable frequency drives (VFDs) are used to control the speed of these motors [17-18]. Since VFD consists

of power electronic switches, the output current of VFD is nonsinusoidal which is directly fed to the induction motor. The harmonics in the motor current results in heating of the motor. Few studies have been reported on active filters connected to motor side in order to provide fundamental current to the motor [19-21].

In this paper, a VFD controlled induction motor is connected to the grid. With the help of the active filter on the motor side, the harmonics in the current at the output of the drive will be eliminated, providing only the fundamental current to the induction motor. Two control strategies namely, synchronous reference frame theory (SRFT) and instantaneous reactive power theory (IRPT) are used. The organization of the paper is as follows: Study system is given in Section 2. Section 3 provides the control of active shunt filter. Section 4 presents the results and discussions. Conclusions are drawn in section 5.

2. SYSTEM CONFIGURATION

General configuration of motor side active filter is as shown in Figure 1. Here active filter is connected in shunt configuration at output of variable frequency drive. An induction motor is connected at the output of the drive. The main objective of active filter is to deliver pure sinusoidal current to the motor. Active filter consists of three-phase voltage source converter consisting of six IGBTs. Switching of these IGBTs are realized from PWM. The control signal to PWM is taken from reference signal generator which generates reference signal using either SRFT or IRPT [22-23]. At ac side, inductors are used to filter high frequency components.

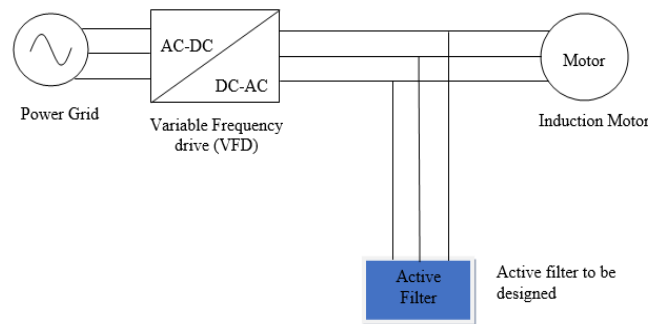


Figure 1. Schematic diagram of the study system with active power filter

3. CONTROL ALGORITHMS

In order to provide fundamental current for the motor using shunt active filter, it is important to obtain harmonic component of load current, as filter has to inject the anti-harmonic component at output of the drive. Two control strategies have been used to generate the reference signal which consists of harmonic component of the load current.

3.1. Synchronous reference frame theory (SRF)

This theory involves transforming the currents in 3-phase domain into synchronously rotating d-q frame [2]. Inputs to the controller are the output currents of VFD feeding the motor and the rotor angle at each instant. Rotor angle is processed to obtain the sine and the cosine signals required for the conversion. The current signals are used to generate the reference signals for the active filter. To generate these signals, the currents in 3-phase ac domain is transformed to α - β domain using Clark's transformation and then to the d-q domain using Park's transformation [24]. The dq currents are filtered to obtain the fundamental component of the current. This is then transformed back to 3-phase ac and subtracted from the load current in order to obtain harmonic components. It is then fed to the PWM signal generator to generate the final switching signals for the inverter. Clark's Transformation is given by (1).

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

The current in α - β frame is converted to d-q frame using Park's transformer as shown in (2).

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2}$$

So, once we obtain current in dq frame then it is filtered using low pass filter (LPF) to obtain fundamental component and is again converted to three phase fundamental current (i_{sa} , i_{sb} , i_{sc}) using Inverse Clarke's and Park's transformation. The compensating currents are obtained by subtracting the extracted fundamental current from the output currents of VFD. The block diagram of synchronous reference theory is as shown in Figure 2.

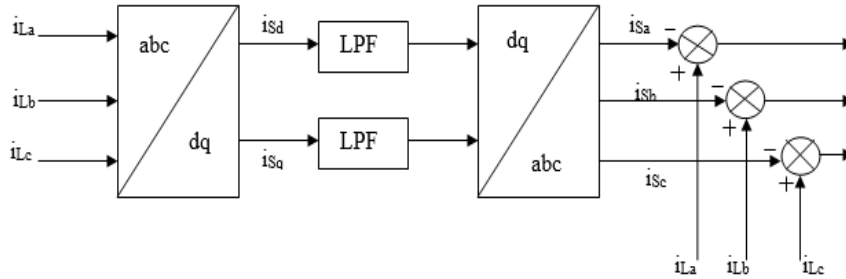


Figure 2. Block diagram of SRF theory [2]

3.2. Instantaneous reactive power theory (IRPT)

The p-q theory is based on instantaneous powers defined in the time domain [22]. In p-q theory, load current and load voltage are converted from abc coordinates to α - β coordinates and then to powers (active and reactive). In this coordinate, power is filtered through the low pass filter to obtain the fundamental component of power which is then converted to fundamental currents in α - β . These current signals are again transformed from α - β to abc coordinates. It is then subtracted from the main component to extract the harmonic component in the load current. The block diagram of IRPT is as shown in Figure 3.

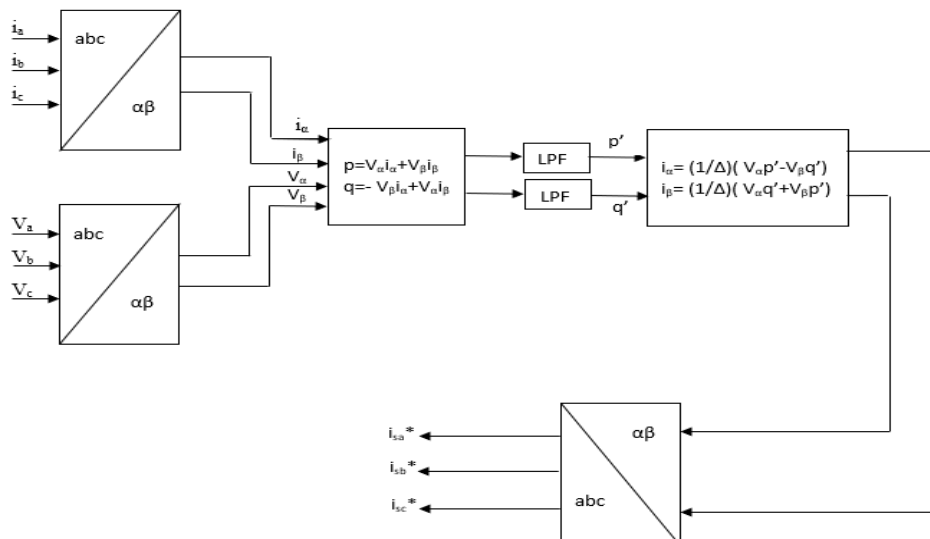


Figure 3. Block diagram of IRPT Theory [2]

Power in the $\alpha\beta$ is calculated as (3).

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} V_0 & 0 & 0 \\ 0 & V_\alpha & V_\beta \\ 0 & V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

This power that is obtained by this conversion is filtered through low pass filter. The filtered power is now converted back to the current in $\alpha\beta$ domain as per the formula (4).

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \left(\frac{1}{V_\alpha^2 + V_\beta^2} \right) \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (4)$$

4. RESULTS AND DISCUSSION

The induction motor drive consists of 12-pulse rectifier connected to the inverter through dc link capacitor. Sinusoidal SPWM switching is used for a 2-level inverter with V/f control. Motor which is connected to the system is pre-defined motor in MATLAB [25] with the power rating of 160kW. Motor side active filter consists of the voltage source inverter. The main purpose of MSAPF is to eliminate the harmonics present in the motor current and to ensure that the fundamental sinusoidal current flows in the motor. Three cases are considered: 1) system without MSAPF, 2) system with MSAPF using SRF technique and, 3) system with MSAPF using IRPT technique.

4.1. System without active filter

The motor current and its frequency spectrum without the presence of MSAPF in the system is shown in the Figure 4. It is observed that the steady state motor current is not sinusoidal. It is also seen from the FFT analysis of the motor current that the THD of the current in the motor side is 13.44% and the peak amplitude of fundamental current is 385.9 A. These harmonics are mainly due to switching frequency of the drive system. According to IEEE-519 standards, the current distortion should be within $\pm 5\%$. The distortion is 13.44% which is more than 5%. Hence, there is a need to reduce harmonic distortion of motor current.

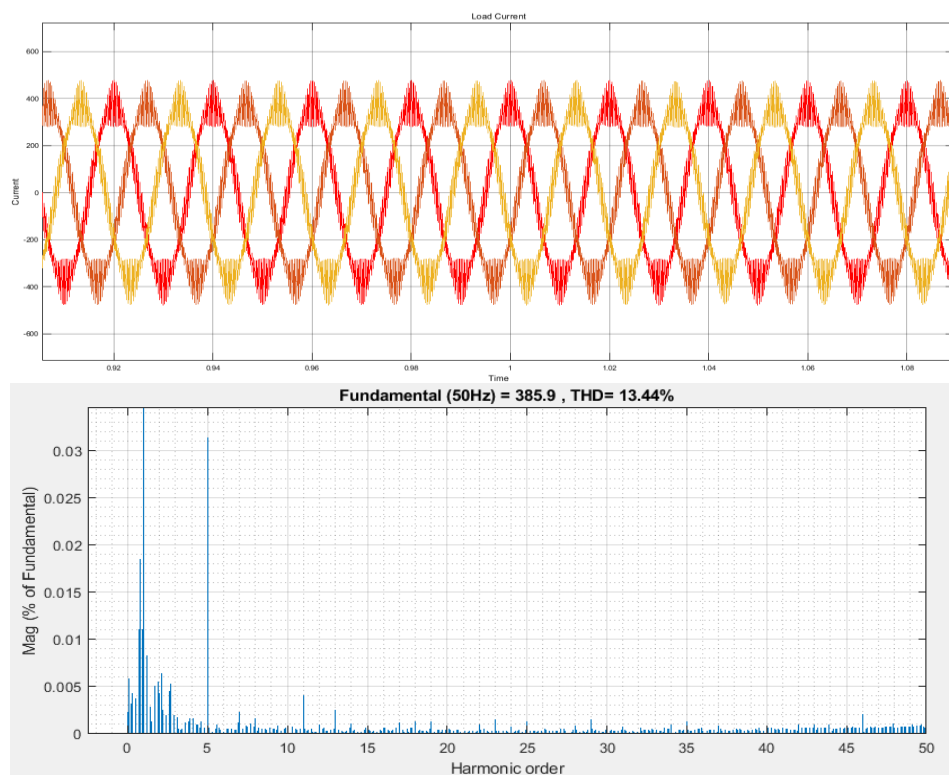


Figure 4. Steady state motor current and its FFT spectrum without MSAPF

4.2. Active power filter using SRF technique

The fundamental current extracted from the output current of VFD with the help of the synchronous reference theory and its harmonic spectrum are shown in Figure 5. The amplitude of the fundamental current is 385.9 A which is same as that of the motor without MSAPF as shown in Figure 4.

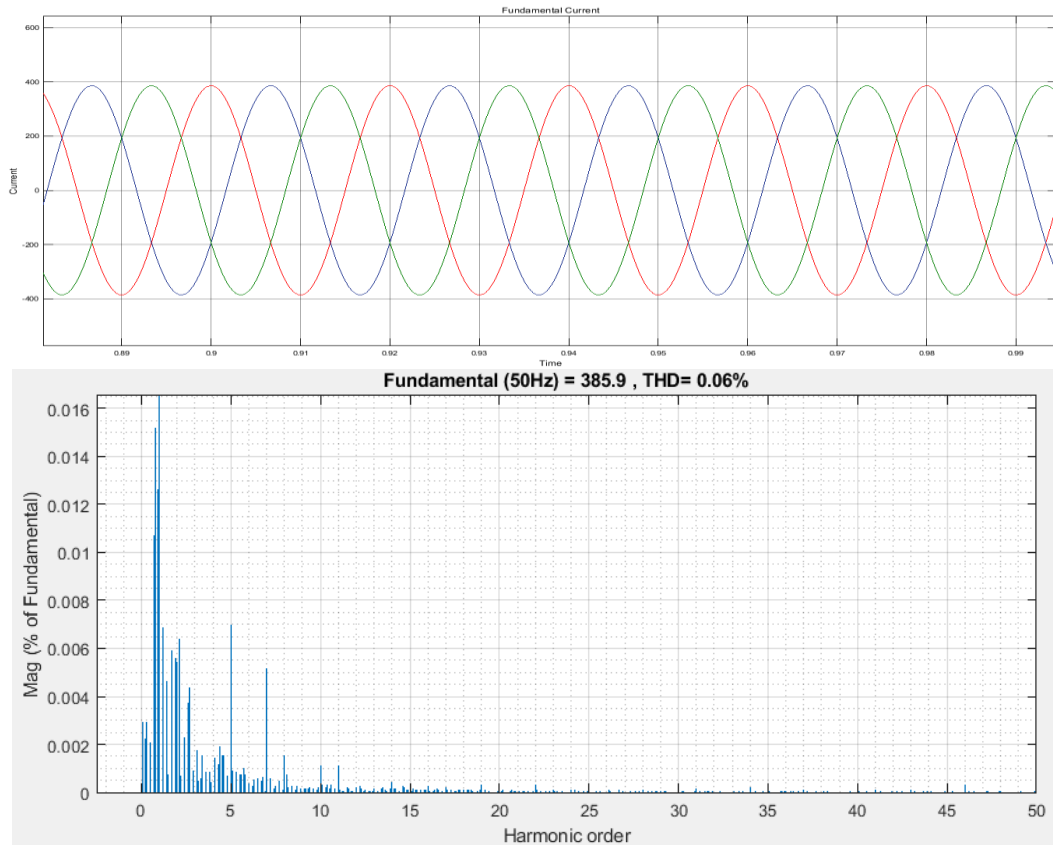


Figure 5. Extraction of fundamental current from the load current and its FFT

When this fundamental current is subtracted from the load current, the compensating current which consists of harmonics except fundamental is obtained. Figure 6 shows the compensating current and its FFT. It is observed that the fundamental current (0.02789) is negligible and indicates that only the harmonic current is extracted from the load current. This is the reference current signal for the active power filter. This current will be injected by PWM inverter into the system.

The current fed to the motor and its frequency spectrum when MSAPF is connected is as shown in Figure 7. It is observed that the THD is 0.13% which is very much less than the THD without MSAPF. The motor current is now composed of fundamental component of 393.6 A with negligible harmonics.

4.3. Active power filter using IRPT technique

Instantaneous reactive power theory is used to generate the reference signal for the inverter. Figure 8 shows the reference current signal (compensating current) obtained using IRPT theory and its harmonic spectrum. THD of compensating current shows a fundamental component of 7A which indicates that the extraction of harmonic components is not as good as SRF technique.

Figure 9 show the motor current and the harmonic spectrum when MSAPF is connected across it. THD of motor current is 0.19% with a fundamental component of 383.6 A. It is seen that the motor current is composed of mainly the fundamental only with the negligible harmonics present.

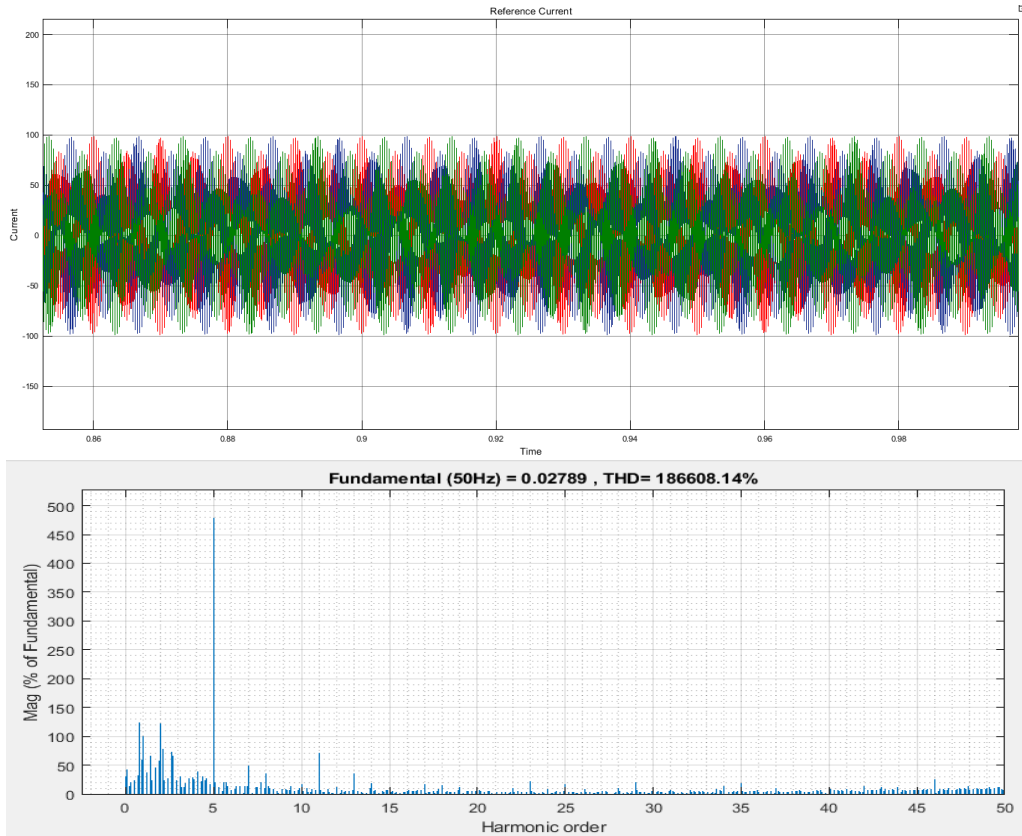


Figure 6. Compensating current and its FFT

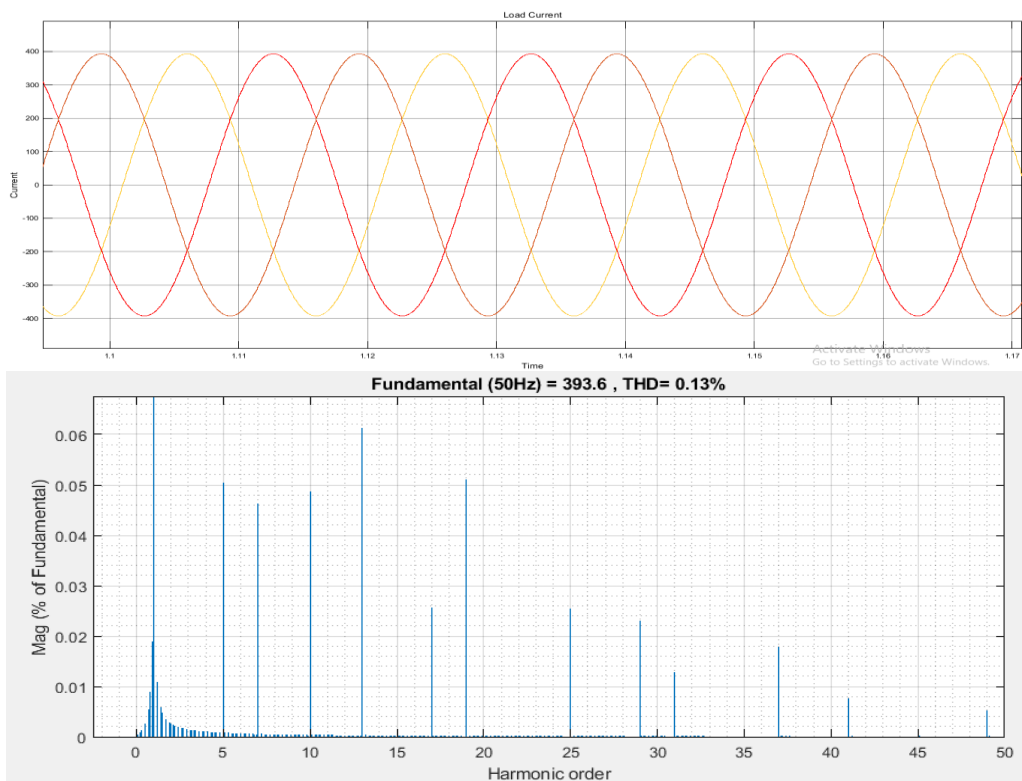


Figure 7. Steady state motor current with MSAPF using SRF theory and the FFT

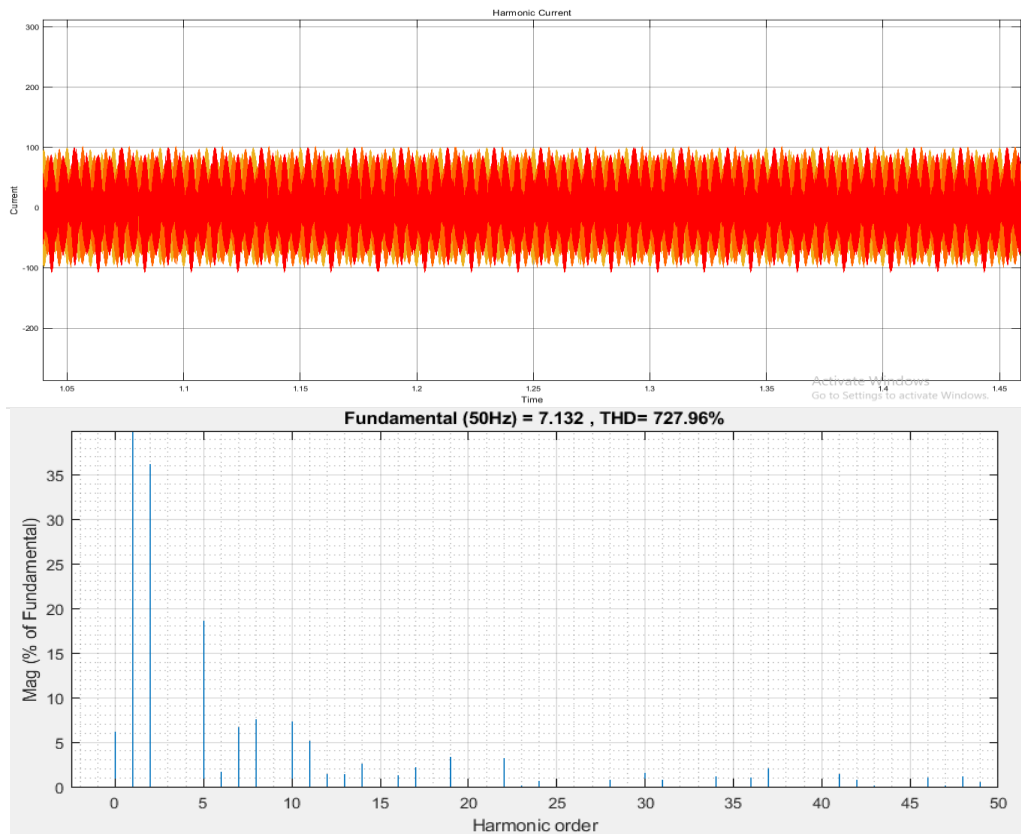


Figure 8. Compensating current and its FFT

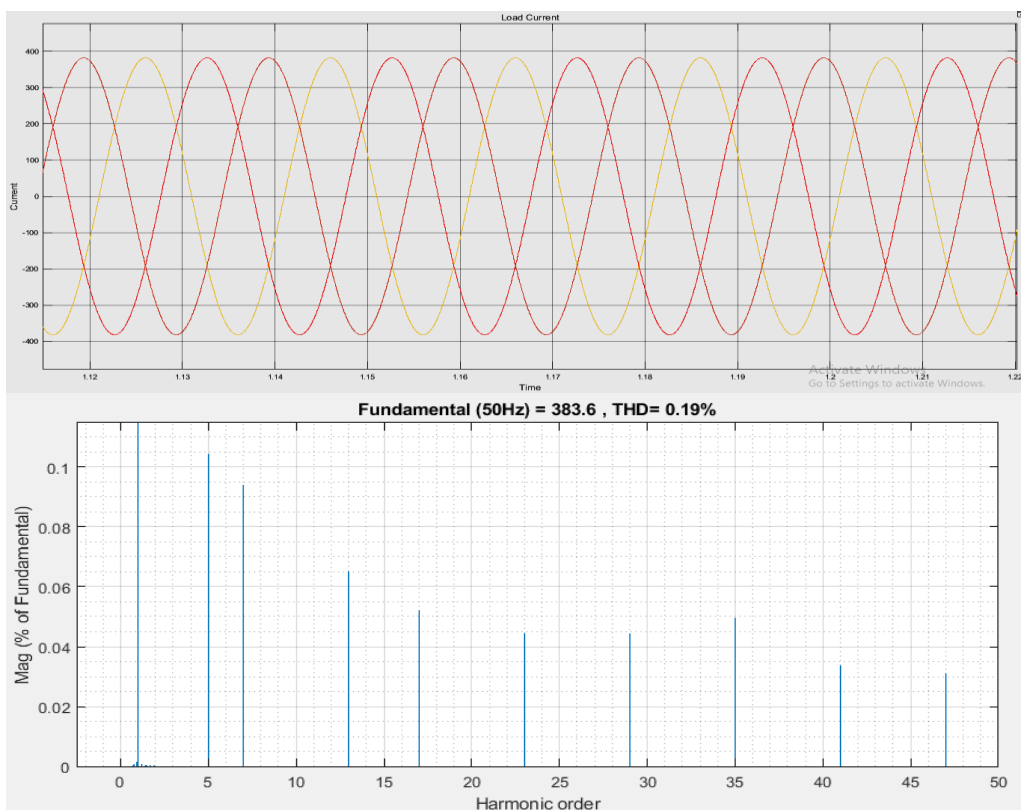


Figure 9. Steady state motor current with MSAPF using IRPT theory

5. CONCLUSION

An active shunt filter connected to the the motor side is designed and simulated. The objective of this active filter is to provide fundamental current to the induction motor so that the motor current is free from the harmonics that is present in the system. Two control methodologies have been implemented namely synchronous reference theory and instantaneous power theory for the generation of reference current signal to PWM converter. Both these controllers perform satisfactorily by significantly reducing the THD of the current supplied to the induction motor. But it is seen that SRF method has the better extraction of the fundamental component as it depends only on VFD current whereas IRPT depends on both current and voltage of the VFD. Due to this SRF shows better control than IRPT.

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