Journal of Engineering and Applied Sciences 12 (Special Issue 7): 8153-8159, 2017
ISSN: 1816-949X

Performance Analysis of Shunt Active Filter with an Adjustable Speed Drive System

T.M. Thamizh Thentral, R. Jegatheesan and K. Vijaya Kumar
Department of EEE, SRM University, Kattakulathur, Chennai, India

Abstract: The quality of the electric power in distribution systems gets retrograded because of the introduction of low order harmonic currents due to non-linearity of adjustable speed drive systems. This substantiality of non-linear loads turns our attention towards power quality in the power distribution systems. In power systems, harmonics are taken as the main problem attributable to the use of power electronic devices in various applications. Active power filters are commonly used to mitigate these harmonics. Three phase shunt active power filters are used to eliminate the harmonics arising due to adjustable speed drive systems fed from voltage source inverter. Synchronous reference frame algorithm is used to extract the compensating currents. The control signal to the three phase shunt active power filter is achieved with the help of hysteresis current control method. The three phase shunt active power filter for current harmonic mitigation with a variable speed drive system as a non-linear load is simulated through MATLAB/Simulink Software and the THD is arrived as per the IEEE 519 recommendations.

Key words: SAPF, harmonics, SRF and power quality, mitigation, recommendations, attributable

INTRODUCTION

Modern day power electronics loads such as electronic/electric-discharge lighting, adjustable-speed drive system, variable frequency drives, SMPS, UPS, electric arc furnace are non-linear loads which tend to cause power quality problems like harmonics interharmonics, voltage fluctuations and power interruption. The harmonic induced on the supply side cause current distortion in the system which deteriorates the power factor and produces voltage distortion. Skin effect is caused due to increment in resistance by the harmonics. Depending on the type of load some particular orders of harmonics are predominant on the system, e.g. in personal computers, 3rd and 5th harmonics are predominant. All these lead to major problems on utility side as well as on the customer side like causing misoperation of metering elements, malfunctioning of protective equipment, additional neutral wire current, damage of microprocessor based equipment, derating of distribution devices leading to resonance. Thermal stress caused by harmonics reduces the operating life of distribution transformers. In accordance with IEEE Std. 519 the harmonics limit on voltage should not exceed 5% of the THD and 3% of the fundamental voltage for any single harmonic. The traditional LC passive filters that are used for harmonic mitigation have some serious drawbacks such as fixed compensation, large configuration size, resonance in the system, etc. Hence, active filters are a promising solution for restraining harmonics within the aforementioned limits. When the active filter is placed in parallel with the load it minimizes the need of compensation power to 20-30% of the load and also ensures redundancy in the design, hence, SAPF filters are used (Bharatiraja *et al*., 2013). This filter is essentially a power filter which injects compensating currents at the PCC, it senses the load current and extracts the harmonics present in it via. generation of reference compensation currents by particular schemes which are then given to a controller for the generation of gating signals for SAPF. This study focuses on one of the reference compensating current generation methods, i.e., the Synchronous Reference Frame (SRF) method.

Active filters: Active filters as the name suggests are those classes of filters that incorporate an active switching device along with a passive energy storage component like capacitors and inductors. Their application is majorly found in low or medium voltage distribution stages where they are used for control of current harmonics and for high voltage levels they are used as voltage or reactive power controllers. Hence, with the help of active filters we can improve reliability, stability and the power quality problems can be resolved. They are widely used as harmonic suppressors and for power factor compensation as well as for power quality management. The major advantage these filters are

Corresponding Author: T.M. Thamizh Thentral, Department of EEE, SRM University, Kattakulathur, Chennai, India

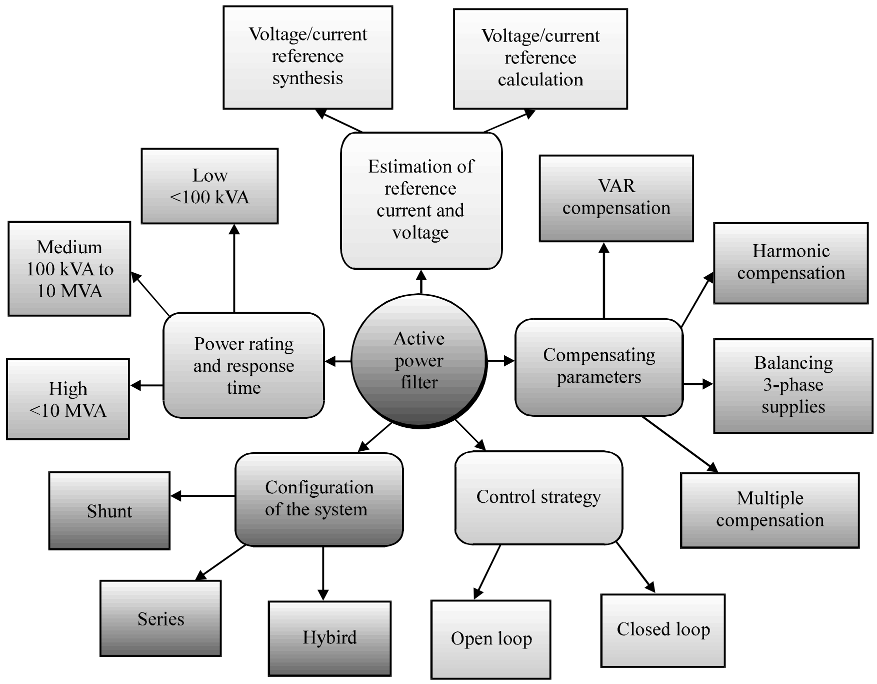

Fig. 1: Types of active power filters

their fast response, flexibility and also they do not introduce resonance into the supply. Figure 1 gives the various types of active power filters based on different functionality. The classification of active filters on the basics of their functionality as.

Power rating and response time based classification: As a general rule the cost is directly related to the response speed of the system which is a major criterion for the selection of a filter. Based on the applications of the filters on power rating and response time the filters used are classified as low power rated applications, medium power applications and high power applications. The filters used in the low power rated applications are generally deal with residential complexes and commercial buildings which have system rated below 100 kVA ranging from small to medium sized loads systems. These systems have a faster response lying within the range of tens of microseconds to milliseconds hence resulting in lowering of power compensation range. These are further classified on basis of the type of system as single phase systems and three phase systems. Single phase systems deal with low power ranges, hence, working at higher frequencies is possible. Depending on balanced or unbalanced loads, three phase inverter configuration or three single phase inverter configuration is used. The filters used for the medium power applications are lie in the range of 100 kVA to 10 MVA. It is applicable for medium to high voltage distribution systems where phase unbalancing effect is neglected. Active filters for these levels of voltages utilised for reactive power compensation are regarded as uneconomical as high currents pose a great difficulty. Thus, alternatives are looked upon such as VAR compensators, static compensator sand synchronous condensers, etc. Response time is in the range of tens of milliseconds. The response time is in the order of few seconds where the filters used in the high power applications.

Classification as per system configuration: The active power filters are classified depends upon the system configuration as, parallel active filters, series active filters and hybrid filters. Parallel active filters are widely used in industrial applications where it cancels out the load current harmonics injected into the supply system and also ensures reactive power compensation. The major advantage of this is the ability to carry compensating current along with a small amount of fundamental current in order to compensate for system losses. This can be further categorized as inverter configurations, lattice structured filters, switched capacitor type and voltage regulator type. Series active filters used in order to maintain a sinusoidal voltage at the load terminals a Pulse Width Modulated (PWM) voltage waveform is either subtracted or added which is done on a instantaneous basis. But on comparison to parallel filter the series active

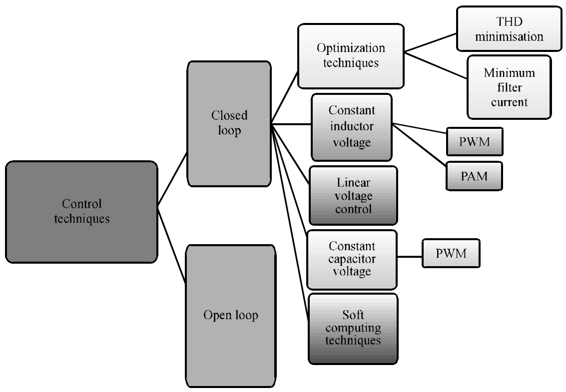

Fig. 2: Various control techniques

filter are less preferred as they require high current rating, lead to more I^2R losses and also the size of filter is larger. But the benefit of using these filters is that they are a promising solution for the removal of voltage waveform harmonics from the system, improve power quality and also balance the three phase voltages. Hybrid filters are either the combination of series or shunt Passive filters and series or parallel active filters.

Classification as per compensating parameters: Depending the parameters to be controlled they can be further classified as reactive power compensation method, harmonics compensation technique, balancing of three phase systems and multiple compensation schemes.

Depending on the control strategy: Figure 2 shows the classification of control strategy. It is mainly classified on the basis of open loop and closed loop systems. The open loop systems use a simple principle for the compensation of harmonics and reactive power. This is done by injecting some amount of power into the system in terms of current. But they don't provide a way to measure how successfully the compensation has occurred. On the other hand, a closed loop control system works along with a feedback loop which is used to sense the parameter to be controlled. These systems are more accurate than open loop systems. These controllers generally employ DSP's and other control techniques.

Classification as per reference compensation method: It can be a time domain/frequency domain approach. The time domain approach generally deals with three phase systems whereas the frequency domain approach is applicable for both single as well as three phase systems. The time domain approach can be furtherclassified as instantaneous reactive power/pq theory, synchronous detection algorithm, constant/unity power factor algorithm, fictitious power compensation, synchronous frame based algorithm, constant active power algorithm and synchronous flux detection method. In the same manner the frequency domain approach is divided as FFT analysis method, sine multiplication method and modified fourier series method. The other soft computing techniques also available which includes neural networks, fuzzy logic methods, optimization methods and estimation schemes to extract the compensating current or voltage.

MATERIALS AND METHODS

Synchronous reference frame method: The synchronous reference frame method is employed as the current compensation method in this study (Palanisamy *et al*., 2016a, b; Sharifian *et al*., 2009; Palanisamy and Vijayakumar, 2017). For the shunt active filter, an infinitely fast controlling action is assumed with an ideal current source. Thus, the calculated reference currents from the SRF method are equal to the compensating currents from the shunt active filter used. This method involves a three axis to two axis transformation. For a shunt active filter, five steps are followed to calculate the currents by this method.

The load currents available in the three phases are transformed to a αβ0 frame, i.e., from (I_{La}, I_{Lb}, I_{Lc}) to $(I_{L\alpha}, I_{L\beta}, I_{L0})$:

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \\ i_{L0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

The components $I_{L\alpha}$ and $I_{L\beta}$ are transformed to the dq-axis:

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}$$

The obtained I_{Ld} and I_{Lq} consist of both the harmonic and fundamental terms. The fundamental terms behave as a DC component (I_{ld}, I_{lq}) whereas the harmonic terms which consist of all the harmonics behave as an AC component $(\tilde{i}_{Ld}, \tilde{i}_{Lq})$:

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \bar{i}_{Ld} + \tilde{i}_{Ld} \\ \bar{i}_{Lq} + \tilde{i}_{Lq} \end{bmatrix}$$

This step involves separation of the two components, i.e., the AC and DC components that were shown in the previous step. For this purpose, a high pass filter is employed whose cut-off frequency is determined by:

$$F_c = \frac{1}{2\pi RC}$$

The harmonic components of the current in dq frame $(\tilde{i}_{Ld}, \tilde{i}_{Lq})$ from the previous step are transformed to αβ frame $(\tilde{i}_{L\alpha}, \tilde{i}_{L\beta})$:

$$\begin{bmatrix} \tilde{i}_{L\alpha} \\ \tilde{i}_{L\beta} \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & -\sin(\omega t) \\ \sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix}$$

The three phase reference currents $(I^*_{ca}, I^*_{cb}, I^*_{cc})$ are calculated for a shunt active power filter. The harmonics on the αβ frame $(\tilde{i}_{L\alpha}, \tilde{i}_{L\beta})$ and the zero current (I_0) are used to determine the reference currents. The input for the applied shunt active power filter is then given by these reference currents, so as to compensate the harmonics of the power system:

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} \tilde{i}_{L\alpha} \\ \tilde{i}_{L\beta} \\ \tilde{i}_{L0} \end{bmatrix}$$

The SRF harmonic reduction method is effectively represented in this block diagram.

RESULTS AND DISCUSSION

Figure 3 describes the enrtire simulation model of the current harmonics occurred by the 3 phase AC induction motor drive system with 3 phase voltage source shuunt active power filter. The output of the filter is injecting the negative harmonic current to the line through the line inductor to reduce the harmics present in the source current. The detailed diagram of the three phase variable speed induction motor drivesystem is considered as the harmonic producing load is shown in Fig. 4.

Figure 5 shows that the source current waveform is not a pure sinusoidal. It is getting distorted due to the non-linearity in the system. Figure 6 gives the FFT analysis of the source current wave form and the THD is 41.99%. Both the diagram is given for the system without filter.

Figure 7 source current after 0.1 sec is become sinusoidal due to the shunt active power filter connected in the system. Figure 8 is the FET analysis for the source current waveform of the system with SAPF filter and the THD is 3.89%.

Table 1 and 2 showed the numerical values of each order of harmonics from fundamental to 20th

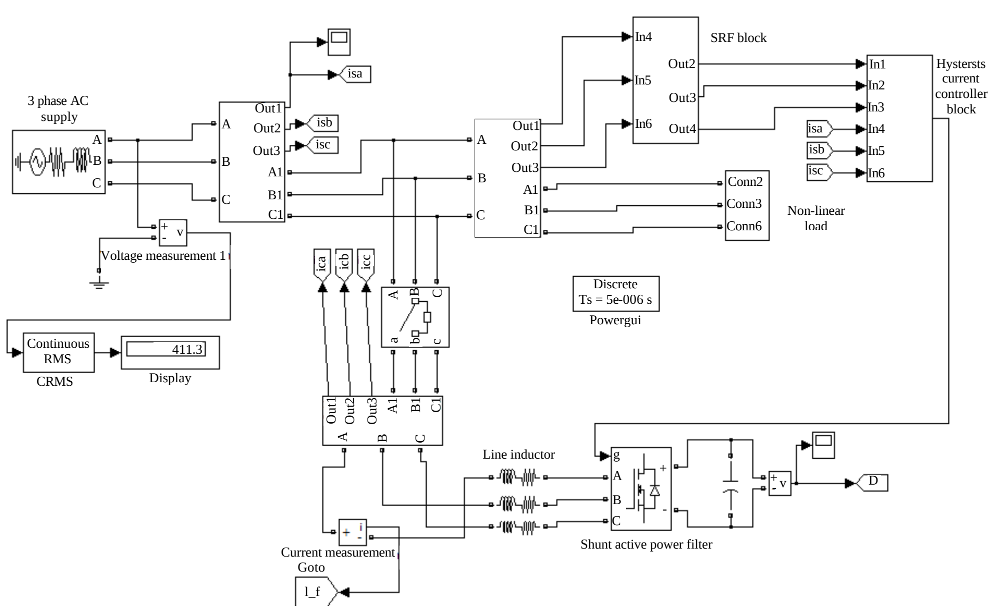

Fig. 3: Simulation circuit with shunt active filter

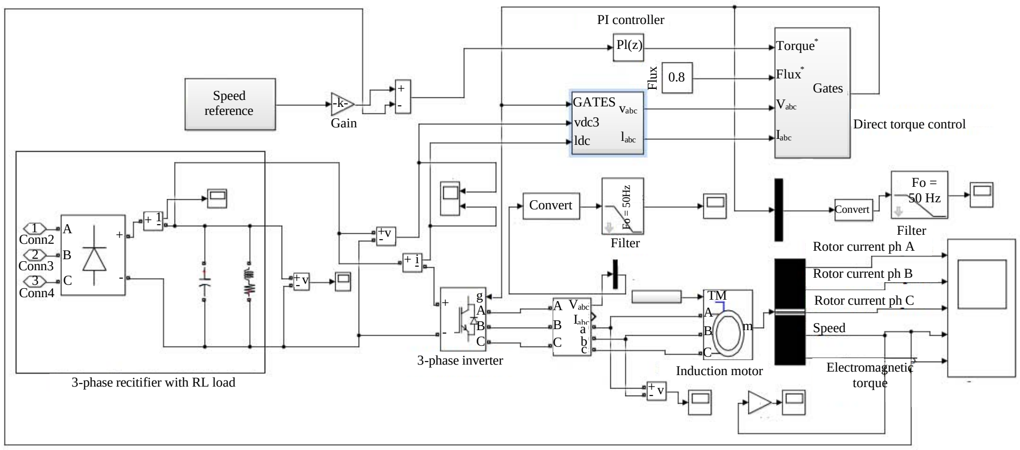

Fig. 4: Load diagram of shunt active filter connected to the system

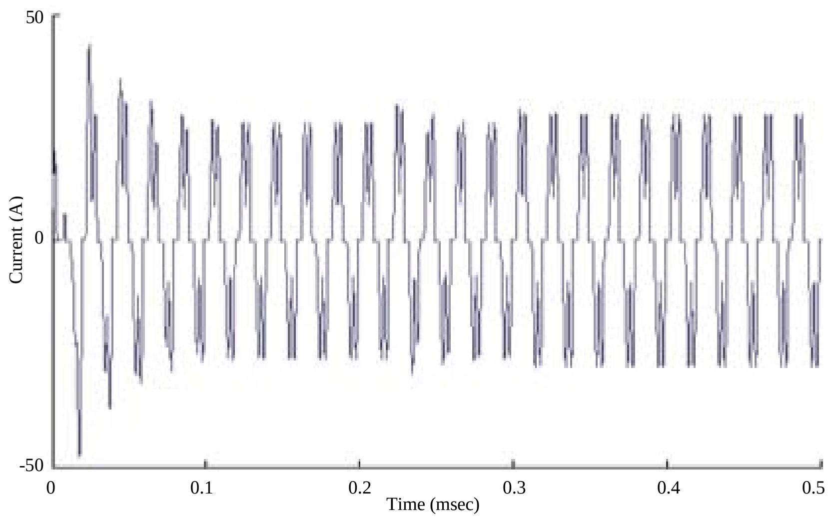

Fig. 5: Source current waveform without SAPF

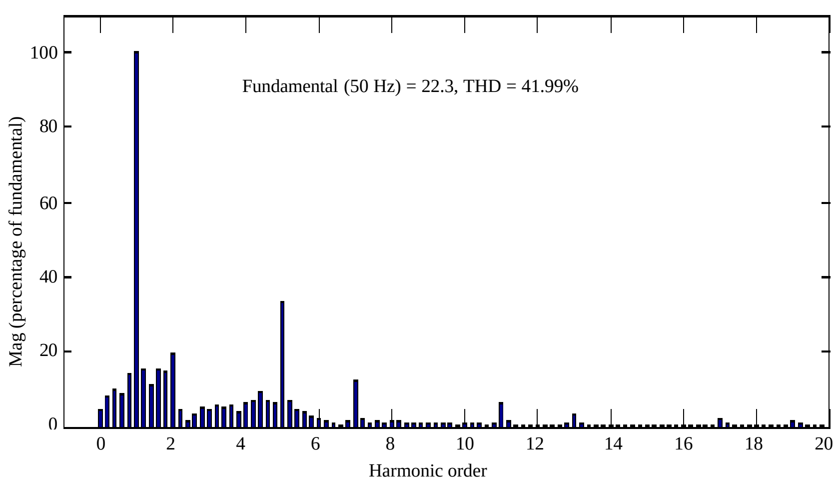

Fig. 6: FFT analysis of source current waveform without SAPF

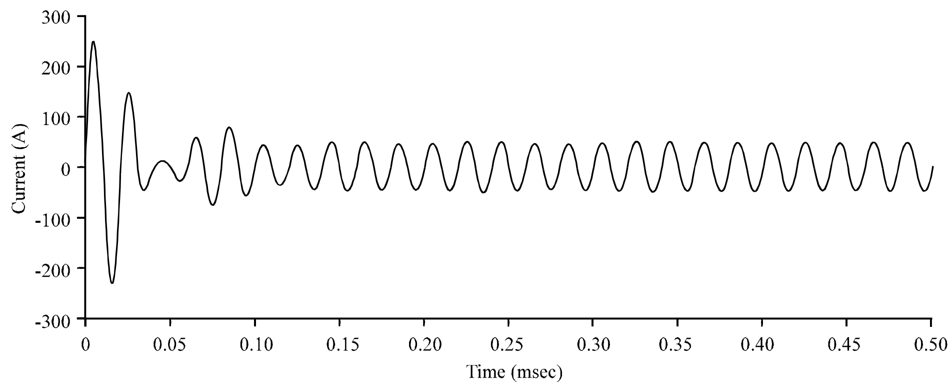

Fig. 7: Source current waveform with SAPF

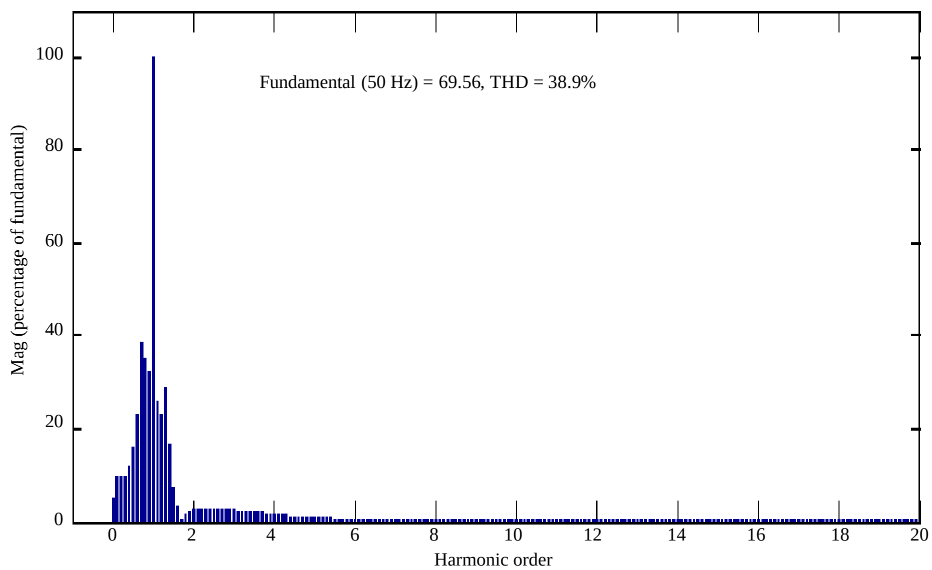

Fig. 8: FFT analysis of source current waveform with SAPF

Table 1: THD analysis without shunt active filter

Harmonic orders	THD (%)
1	100.00
2	1.58
3	0.53
4	0.68
5	37.8.
6	0.24
7	13.06
8	0.09
9	0.08
10	0.06
11	6.54
12	0.11
13	3.19
14	0.06
15	0.04
16	0.03
17	2.73
18	0.07
19	1.83
20	0.03

Table 2: THD analysis with shunt active filter

Harmonic orders	THD (%)
1	100.00
2	2.38
3	2.34
4	1.50
5	0.83
6	0.51
7	0.49
8	0.38
9	0.22
10	0.14
11	0.10
12	0.06
13	0.30
14	0.06
15	0.06
16	0.06
17	0.06
18	0.07
19	0.06
20	0.05

order. It is clear that from Table 1 only the 5th and 7th harmonic is having higher percentage of THD. For going higher frequencies it is getting reduced. Table 2 shows the reduction in the 5th and 7th harmonic order.

CONCLUSION

In this study, using SRF control method compensation of source current to mitigate the harmonics is carried out. Digital simulation in MATLAB/Simulink environment has been carried out using a shunt active power filter with an AC drive as the load and it is compared with a circuit without using a filter.

The comparative summary of THD levels for the corresponding orders of harmonics has been tabulated. The simulation of SAPF circuit is started at 0.2 sec. The distortion in the input current waveform has been lowered with THD reduced to 3.89 from 41.99%. This is in accordance with the IEEE 519 Std. and the THD is limited within the 5% THD level criterion.

REFERENCES

Bharatiraja, C., S. Raghu and K.R.S. Rao, 2013. Comparative analysis of different PWM techniques to reduce the common mode voltage in three-level neutral-point- clamped inverters for variable speed induction drives, Int. J. Power Elect. Drive Sys. 3: 105-116.

Palanisamy, R. and K. Vijayakumar, 2017. Maximum boost control for 7-level Z-source cascaded H-bridge inverter. Intl. J. Power Electron. Drive Syst., 8: 739-746.

Palanisamy, R., A.U. Mutawakkil and K. Vijayakumar, 2016b. Hysteresis SVM for coupled inductor Z source diode clamped 3-level inverter based grid connected PV system. Intl. J. Power Electron. Drive Syst., 7: 1181-1192.

Palanisamy, R., K. Vijayakumar, K. Nikhil, M. Iyer and R. Rao, 2016a. A proposed SVM for 3-level transformer-less dual inverter scheme for grid connected PV system. Indian J. Sci. Technol., 9: 1-7.

Sharifian, M.B.B., Y. Mohamadrezapour, M. Hosseinpour and S. Torabzade, 2009. Single-stage grid connected photovoltaic system with reactive power control and adaptive predictive current controller. J. Applied Sci., 9: 1503-1509.