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Analysis and Mitigation of Harmonics in an Induction Motor using Passive Filter at Varying Loads

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ABSTRACT

The objective of the electric utility is to deliver sinusoidal voltage at fairly constant magnitude throughout the system. As the load is more non linear, complexity will increase more so these non linear loads produces harmonic currents. Harmonic distortions are increasing rapidly due to use of non linear loads so it is very important to mitigate these harmonics. In this paper, the harmonic producing loads like three phase induction motor is analyzed. Measurements are further carried out using power quality analyzer (Meco PHA-5850) to evaluate the total harmonic distortion (THD) of current. In this paper, Harmonic analysis and mitigation of three phase induction motor with shunt passive filteris done. Harmonics are studied under different load conditions such as no load, half load, and full load and blocked rotor load conditions. Total harmonic distortion (THD) is more due to the 3rd and 5th harmonic present in the three phase induction motor so the shunt passive filter is designed to mitigate the 3rd and 5thorder harmonics and the overall THD.

***Key words**:* Three phase induction motor, Power quality analyzer, Passive filter, Harmonics, total harmonic distortion (THD).

I. INTRODUCTION

(A) Three phase induction motor

The present deregulated industry has led to the introduction of power quality problems in the power system which is quite challenging in the long run and has become one of the major concerns in recent years [1]. Due to the increasing number of harmonic producing loads, the problem of their impact on the power system needs further consideration.

This paper considers one of the major harmonic producing loads i.e. three phase induction motor. In this paper, three phase squirrel cage induction motor is studied with the help of Power Quality Analyzer. 50 Hz frequency is taken as fundamental frequency. Experimental analysis of 3 HP, 415 V, 4.5 Amps, 1440 RPM three phase squirrel cage motor is done with the help of PQA. Further harmonic analysis under different loading conditions such as no load, half load, full load, block rotor is done. The most commonly used harmonic index to calculate the harmonic distortions is called Total Harmonic Distortion (THD) which is the ratio of sum of powers of all the harmonic components to the power of the fundamental.

$$THD = \frac{\sqrt{(V_2^{\,2} + V_3^{\,2} + V_4^{\,2} + ... + V_n^{\,2})}}{V_1} * 100 \tag{1}$$

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(B) Harmonics

A harmonic is a signal or wave whose frequency is an integer multiple of frequency of the fundamental signal. Let say if *f* is the fundamental or main frequency(usually 50 or 60Hz) of the signal then 2*f* is the frequency of the second harmonic, 3*f* is the frequency of the third harmonic and so on[2].

Fh= (h) * fundamental frequency of the signal

Where h is the integer value, so first harmonic will be the fundamental frequency. Now the 3rd harmonics will be given by above formula having 50 Hz frequency

F3= 3* 50= 150 Hz and similarly 5th and 7th harmonic as 5*50= 250 Hz and 7* 50= 350 Hz

(C) Effect of harmonics on performance of three phase induction motor

The harmonics present in the induction motor are time and space harmonics. The time harmonics are present in the input supply of the three phase induction machine. The source may contain odd harmonics such as 3rd, 5th and 7th harmonics.

Even ordered harmonics can't be present due to the symmetry of the waveform as f(t)= -f(t+ T/2). Let the r phase of the machine is given by

$$V_R = V_{1m}\sin(\omega_1 t + \phi_1) + V_{3m}\sin(3\omega_3 t + \phi_3) + V_{5m}\sin(5\omega_5 t + \phi_5) + V_{7m}\sin(\omega_7 t + \phi_7) \quad (2)$$

Assuming that it is a balanced three phase supply v_Y and v_B are 120° and 240° shifted from v_R respectively.then the expression for v_Y and v_B are given by

$$V_Y = V_{1m}\sin(\omega_1 t + \phi_1 - \frac{2\pi}{3}) + V_{3m}\sin(3\omega_3 t + \phi_3 - 3*\frac{2\pi}{3}) + V_{5m}\sin(5\omega_5 t + \phi_5 - 5*\frac{2\pi}{3}) + V_{7m}\sin(\omega_7 t + \phi_7 - 7*\frac{2\pi}{3})$$

$$V_B = V_{1m}\sin(\omega_1 t + \phi_1 - \frac{4\pi}{3}) + V_{3m}\sin(3\omega_3 t + \phi_3 - 3*\frac{4\pi}{3}) + V_{5m}\sin(5\omega_5 t + \phi_5 - 5*\frac{4\pi}{3}) + V_{7m}\sin(\omega_7 t + \phi_7 - 7*\frac{4\pi}{3}) \quad (4)$$

Now if we consider third harmonic component of the three phase waveforms, and if Vx3 (t) is the third harmonic of phase x, we can see that

$$V_{R3} = V_{3m}\sin(3\omega_1 t + \phi_3)$$

$$V_{Y3} = V_{3m}\sin(3\omega_1 t + \phi_3)$$

$$V_{B3} = V_{3m}\sin(3\omega_1 t + \phi_3) \quad (5)$$

Therefore, we come to know that third harmonic components are in phase. In star connected system with isolated neutral it will not cause any current to flow. if neutral is connected to the system, there will be current flowing but this is a rare condition in induction machine.so the machine is therfore an open circuit to the third harmonics also called as triplen harmonics.in fact one can see that any harmonic component which is a multiple of three will face an identical situation. So these will not have any effect on the induction machine.

Let us now consider the fifth harmonic, form the above equations one can see that

$$V_{R5} = V_{5m}\sin(5\omega_1 t + \phi_5)$$

$$V_{Y5} = V_{5m}\sin(5\omega_1 t + \phi_5 - 5*\frac{2\pi}{3})$$

$$= V_{5m}\sin(5\omega_1 t + \phi_5 - 5*\frac{4\pi}{3})$$

$$V_{B5} = V_{5m}\sin(5\omega_1 t + \phi_5 - 5*\frac{4\pi}{3})$$
$$= V_{5m}\sin(5\omega_1 t + \phi_5 - \frac{2\pi}{3}) \quad (6)$$

From eqn. 6 we concluded that fifth harmonic forms a negative sequence which causes backward revolving flux pattern as compared to the fundamental frequency at their respective synchronous speeds.

Space harmonics are due to the non- sinusoidal distribution of the coils in the machine and slotting. Practically, air gap mmf and flux are non sinusoidally distributed in space.

II. PROPOSED METHODS OF HARMONIC ELIMINATION

(A) Passive shunt filter

Passive shunt filter is the most commonly filter used for current harmonic distortion in th system. These filters are connected in shunt with the load in the system.

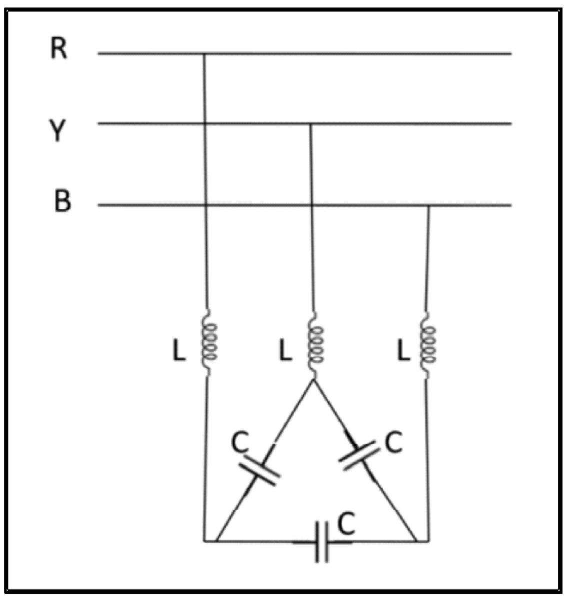


Figure 1: Figure showing typical passive filter used for current harmonic mitigation

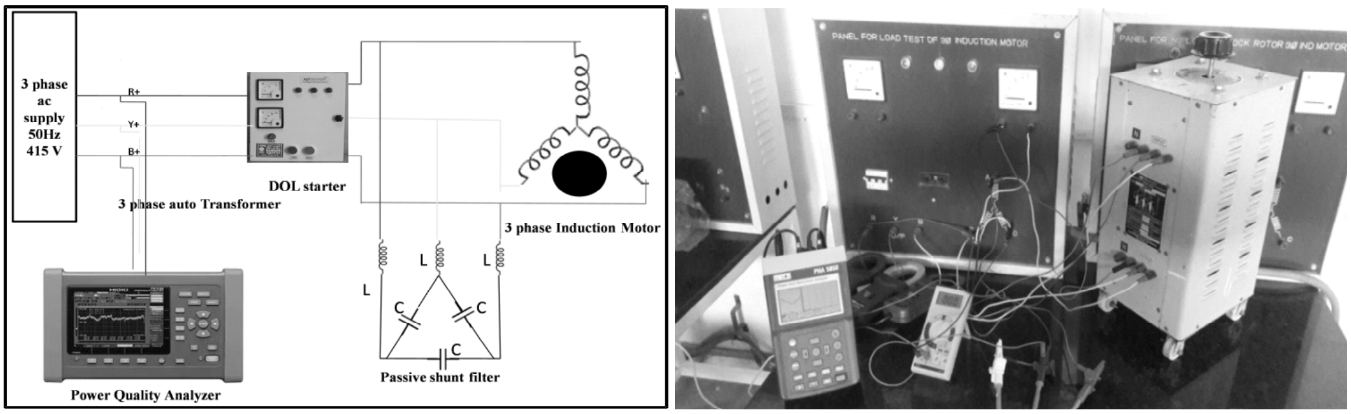
They are used to mitigate current source type of harmonic producing loads. Passive filters offers a low impedance path to divert all the harmonic components of current. It has the tendency to offer some reactive power to the circuit so it is used for tweo purposes one for the filtering purpose and other for reactive compensation purpose to correct the power factor in the circuit [3]. The passive filter is designed to mitigate the 3rd and 5th order harmonics and the overall current THD. The L and C values are 6mH and 6.5 mF. Figure 1 shows typical passive filter used for current harmonic mitigation.

III. EXPERIMENTAL ANALYSIS

In this paper, 3 HP,415 V, 4.5 Amps, 1440 RPMthree phase squirrel cage induction motor is connected with the Power Quality Analyzer for the harmonic analysis. Analysis is done for different varying loads of induction machine such as no load, half load, full load and blocked rotor load and then the mitigation of current harmonics is done with the shunt passive filter. Shunt passive filter is connected in parallel in the system with the load.The L and C values are 6mH and 6.5 mF.

In case of No Load condition as the name suggests output power delivered is zero i.e. the output work is zero although rotor is rotating as the output torque is zero. As the minimum current rating of the machine is 2.8 A without any load so the current will be adjusted to 2.8 A and the load is adjusted along with.In case of Half Load condition, As the maximum current rating of the 3 phase squirrel cage induction motor is 4.5 A , the load will be adjusted as half the maximum current rating to be 3.67.

In case of Full Load condition, output work or power is maximum. As the maximum current rating of the 3 phase squirrel cage induction motor is 4.5 A, the load will be adjusted as the maximum current rating to be 4.5A and then the machine is at full load condition. In case of blocked rotor load condition, the rotor of the three phase induction motor is blocked and the readings are taken with the power quality analyzer.The block diagram and the picture of the setup at varying loads are shown in Figure 2.



(a) Experimental setup (b) pictorial setup

Figure 2: Figure showing experimental setup of three phase induction motor with passive shunt filter

IV. RESULTS AND DISCUSSIONS

Data collection and analysis was performed on 3 phase squirrel cage induction motor using PQA. In this paper, the harmonic analysis of three phase induction motor is done with the power quality analyzer and 3rd and 5th harmonics is found to be more predominant. The harmonic mitigation is done with the help of passive filter. The harmonics analysis and mitigation is studied for the three phase induction motor under different load conditions and they are summarized as below.

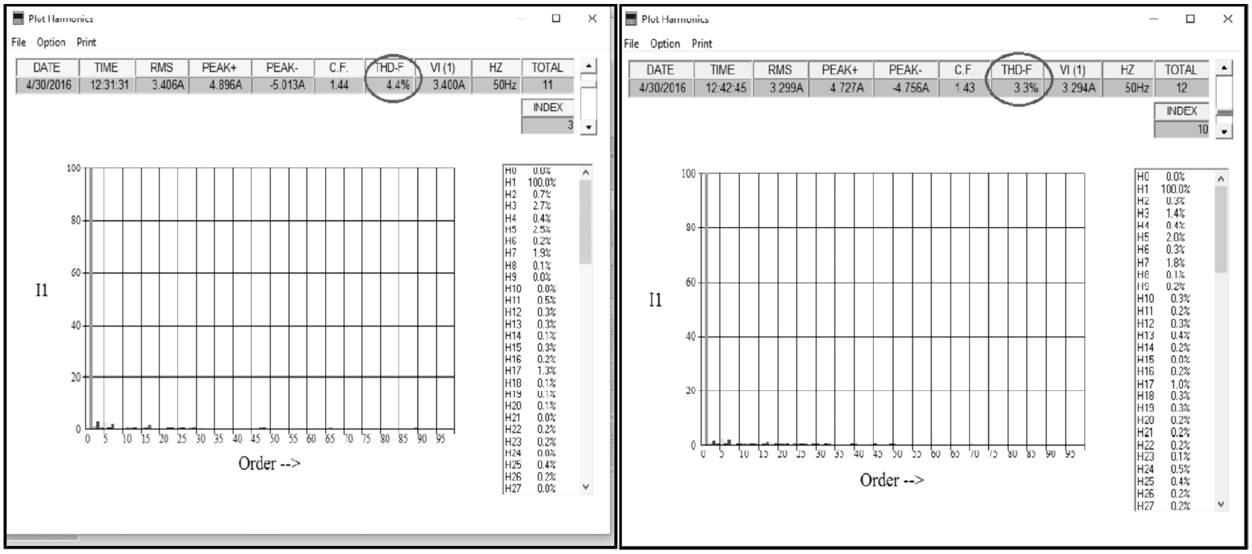
CASE 1. Harmonics mitigation at No Load

(A) For Current I_1

For I_1, Harmonics mitigation is done using passive filter. From Table 1, it is observed that THD is reduced from 4.4% to 3.3% using passive filter. The 3rd and 5th harmonics were 2.7% and 2.5% and found to be more predominant without using filter and it is reduced to 1.4% and 2.0% by using passive filter.

Table 1
Harmonic analysis of three phase induction motor at no load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	2.7	1.4
2.	5th	2.5	2.0
3.	**I_{THD}**	**4.4**	**3.3**



(a) Without passive filter **(b) With passive filter**

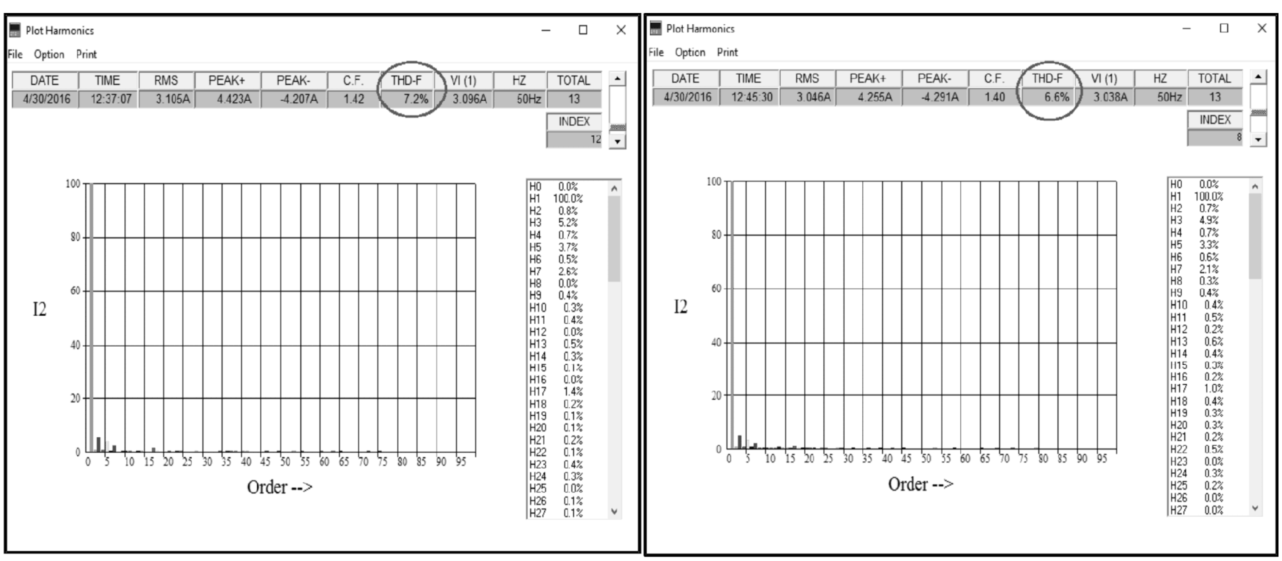
Figure 3. Harmonic analysis of three phase induction motor with and without passive filter.

(B) For Current I_2

For I_2, Harmonics mitigation is done using passive filter. From Table 2, it is observed that THD is reduced from 7.2% to 6.6% using passive filter. The 3rd and 5th harmonics were 5.2% and 3.7% and found to be more predominantwithout using filter and it is reduced to 4.9% and 3.3% by using passive filter.

Table 2
Harmonic analysis of three phase induction motor at no load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	5.2	4.9
2.	5th	3.7	3.3
3.	$\mathbf{I_{THD}}$	**7.2**	**6.6**



(a) Without passive filter (b) With passive filter

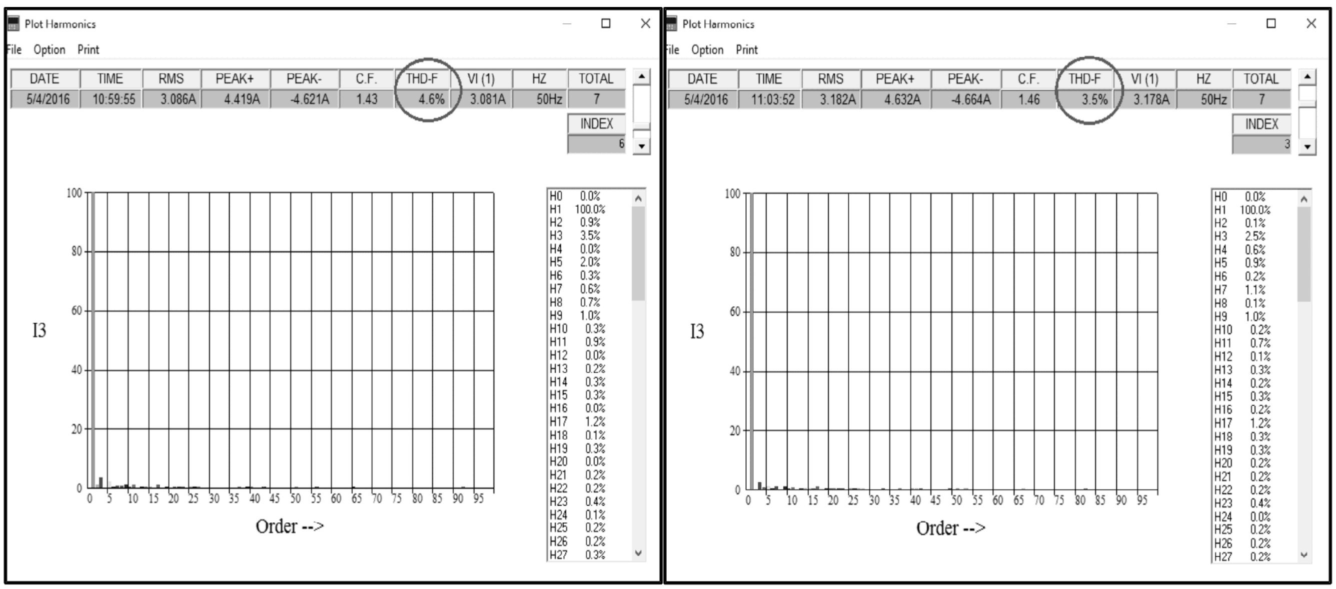
Figure 4. Harmonic analysis of three phase induction motor with and without passive filter

(B) For Current I_3

For I_3, Harmonics mitigation is done using passive filter. From Table 3, it is observed that THD is reduced from 4.6% to 3.5% using passive filter. The 3rd and 5th harmonics were 3.5% and 2.0% and found to be more predominant without using filter and it is reduced to 2.5% and 0.9% by using passive filter.

Table 3
Harmonic analysis of three phase induction motor at no load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	3.5	2.5
2.	5th	2.0	0.9
3.	**I_{THD}**	**4.6**	**3.5**



(a) Without passive filter (b) With passive filter

Figure 5: Harmonic analysis of three phase induction motor with and without passive filter

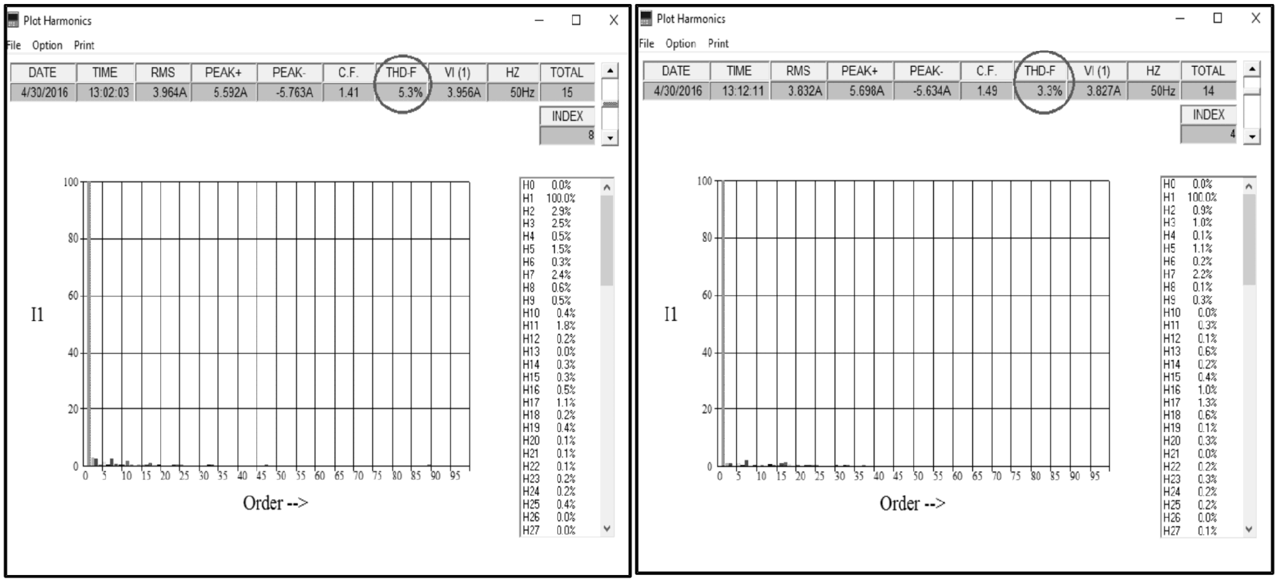
CASE 2. Harmonics mitigation at Half Load

(A) For Current I_1

For I_1, Harmonics mitigation is done using passive filter. From Table 4, it is concluded that THD is reduced from 5.3% to 3.3% using passive filter. The 3rd and 5th harmonics were 2.5% and 1.5% and found to more predominant without using filter and it is reduced to 1.0% and 1.1% by using passive filter.

Table 4
Harmonic analysis of three phase induction motor at half load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	2.5	1.0
2.	5th	1.5	1.1
3.	**I_{THD}**	**5.3**	**3.3**



(a) Without passive filter (b) With passive filter

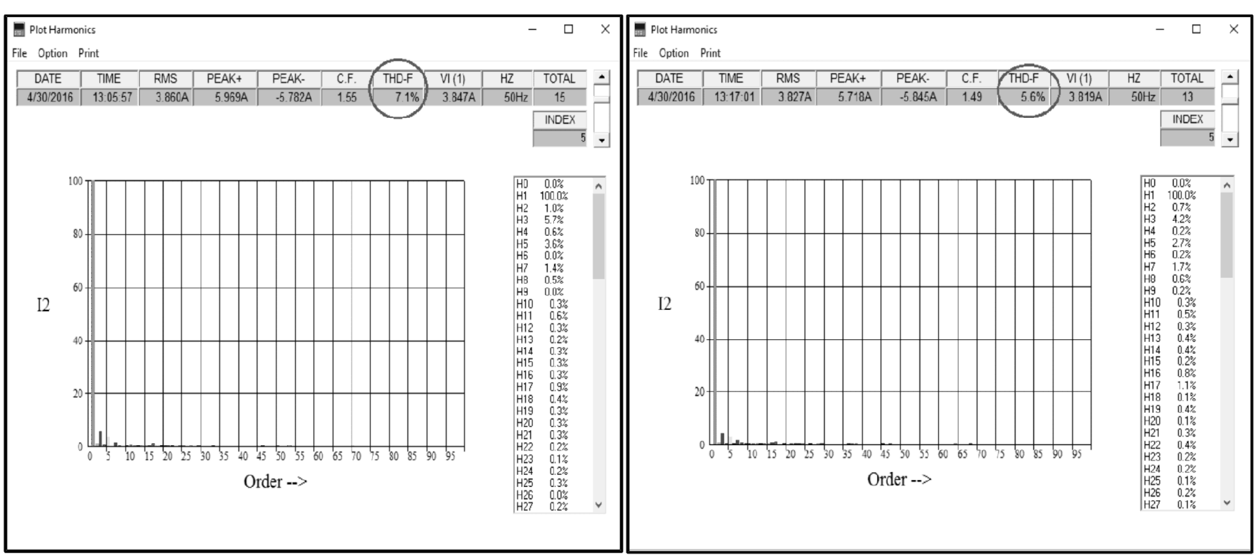
Figure 6: Harmonic analysis of three phase induction motor with and without passive filter

(B) For Current I_2

For I_2, Harmonics mitigation is done using passive filter. From Table 5, it is concluded that THD is reduced from 7.1% to 5.6% using passive filter. The 3rd and 5th harmonics were 5.7% and 3.6% without using filter and it is reduced to 4.2% and 2.7% by using passive filter.

Table 5
Harmonic analysis of three phase induction motor at half load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	5.7	4.2
2.	5th	3.6	2.7
3.	**I_{THD}**	**7.1**	**5.6**

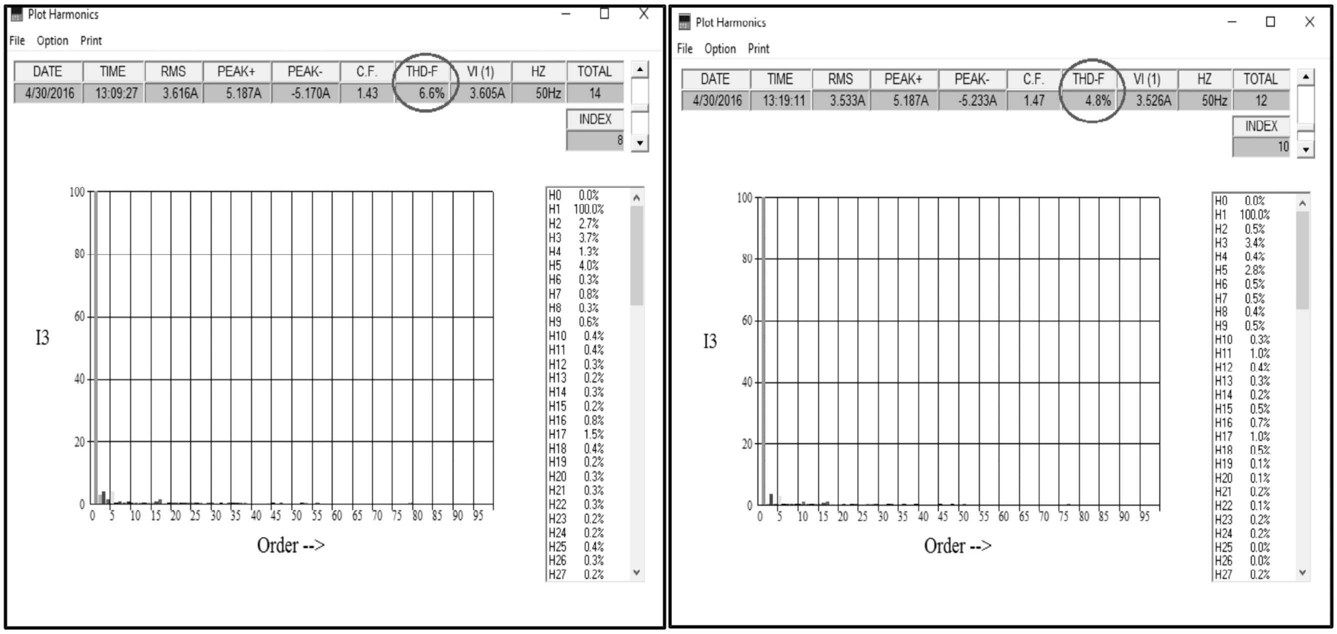


(a) Without passive filter (b) With passive filter

Figure 7: Harmonic analysis of three phase induction motor with and without passive filter

(C) For Current I_3

For I_3, Harmonics mitigation is done using passive filter. From Table 6, it is concluded that THD is reduced from 6.6% to 4.8% using passive filter. The 3rd and 5th harmonics were 3.7% and 4.0% without using filter and it is reduced to 3.4% and 2.8% by using passive filter.



(a) Without passive filter (b) With passive filter

Figure 8: Harmonic analysis of three phase induction motor with and without passive filter

Table 6
Harmonic analysis of three phase induction motor at half load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	3.7	3.4
2.	5th	4.0	2.8
3.	$\mathbf{I_{THD}}$	**6.6**	**4.8**

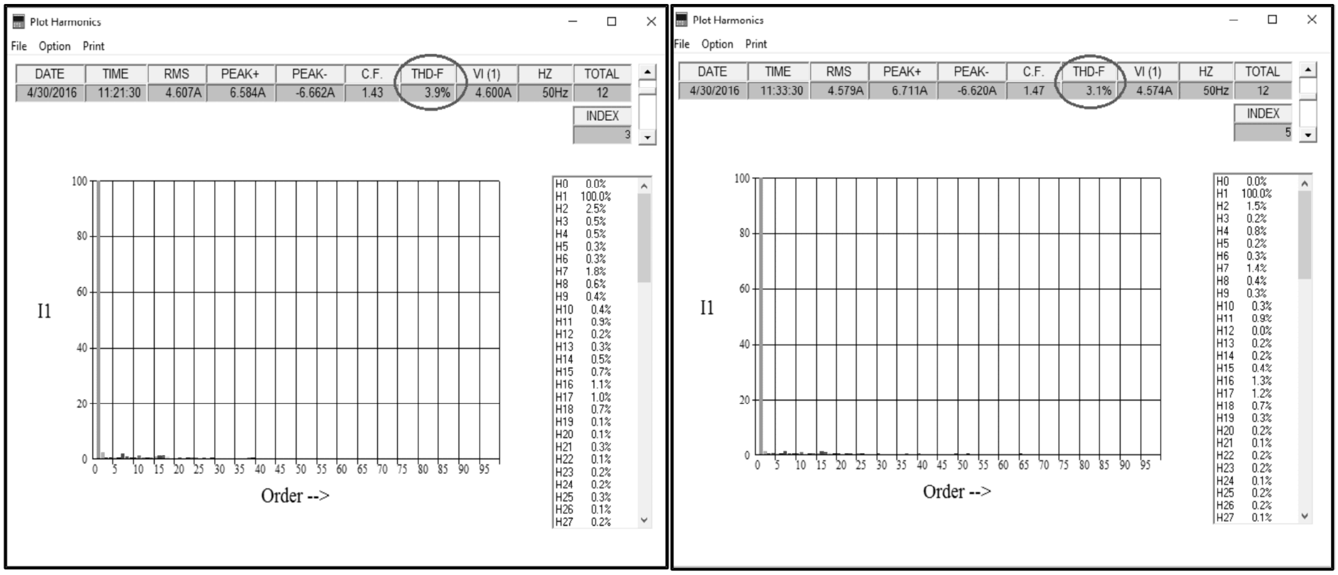
CASE 3. Harmonics mitigation at Full Load

(A) For Current I_1

For I_1, Harmonics mitigation is done using passive filter. From Table 7, it is concluded that THD is reduced from 3.9% to 3.1% using passive filter. The 3rd and 5th harmonics were 0.5% and 0.3% without using filter and it is reduced to 0.2%.

Table 7
Harmonic analysis of three phase induction motor at full load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	0.5	0.2
2.	5th	0.3	0.2
3.	$\mathbf{I_{THD}}$	**3.9**	**3.1**



(a) Without passive filter (b) With passive filter

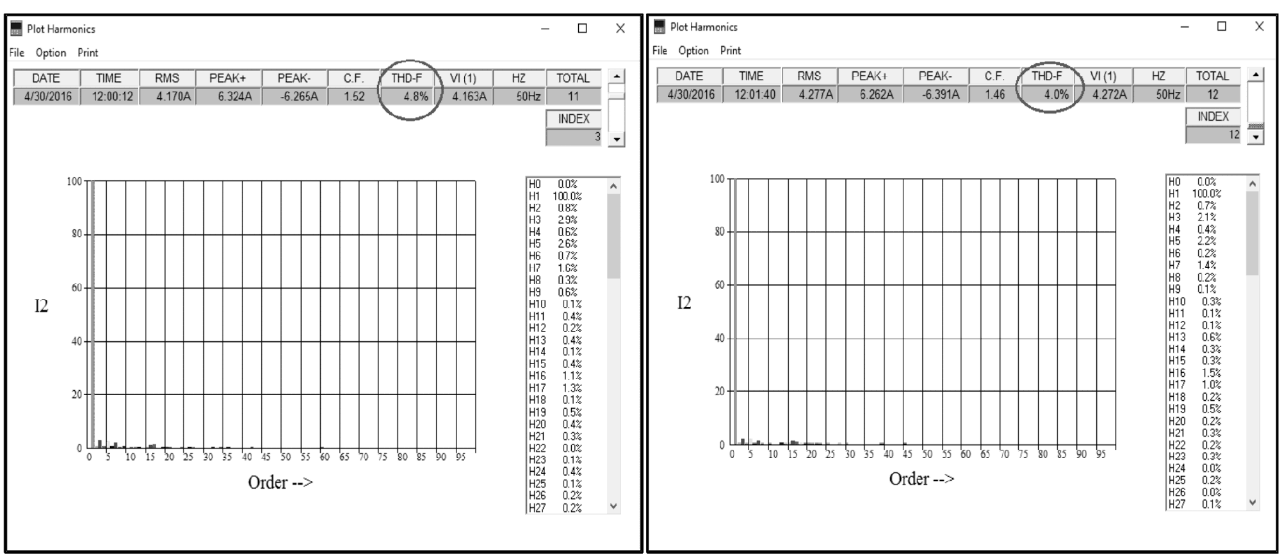
Figure 9: Harmonic analysis of three phase induction motor with and without passive filter

(B) For Current I_2

For I_2, Harmonics mitigation is done using passive filter. From Table 8, it is concluded that THD is reduced from 4.8% to 4.0% using passive filter. The 3rd and 5th harmonics were 2.9% and 2.6% without using filter and it is reduced to 2.1% and 2.2% by using passive filter.

Table 8
Harmonic analysis of three phase induction motor at full load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	2.9	2.1
2.	5th	2.6	2.2
3.	$\mathbf{I_{THD}}$	**4.8**	**4.0**



(a) Without passive filter (b) With passive filter

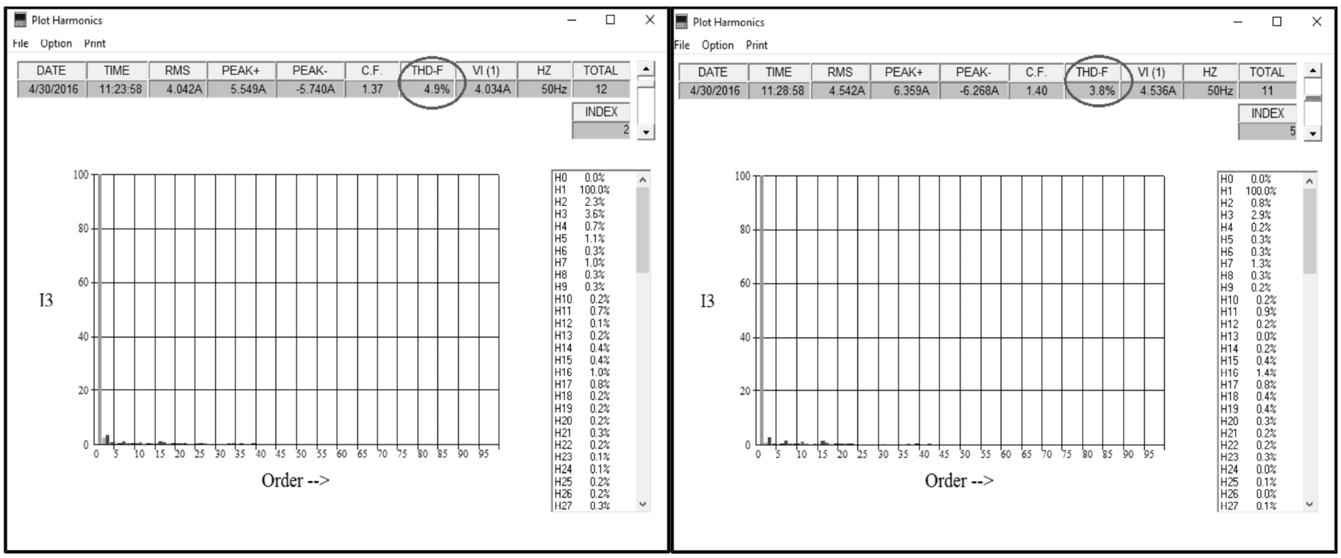
Figure 10: Harmonic analysis of three phase induction motor with and without passive filter

(C) For Current I_3

For I_1, Harmonics mitigation is done using passive filter. From Table 9, it is concluded that THD is reduced from 3.9% to 3.1% using passive filter. The 3rd and 5th harmonics were 0.5% and 0.3% without using filter and it is reduced to 0.2% and 0.2% by using passive filter.

Table 9
Harmonic analysis of three phase induction motor at full load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	3.6	2.9
2.	5th	1.1	0.3
3.	$\mathbf{I_{THD}}$	**4.9**	**3.8**



(a) Without passive filter (b) With passive filter

Figure 11. Harmonic analysis of three phase induction motor with and without passive filter

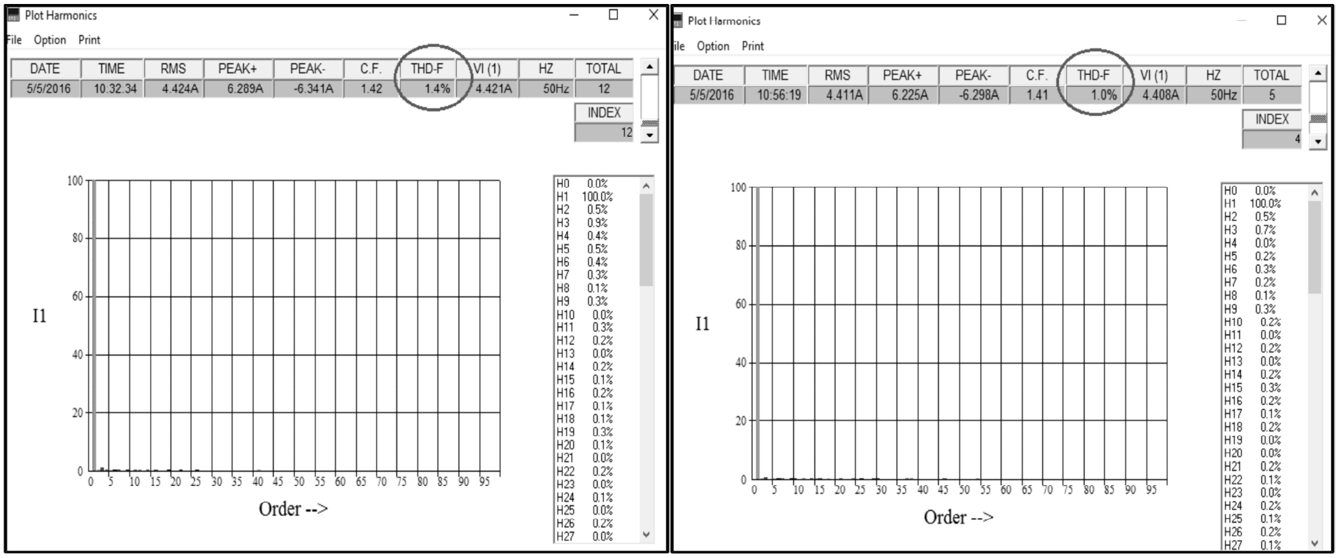
CASE 4. Harmonics mitigation at Blocked rotor Load

(A) For Current I_1

For I_1, Harmonics mitigation is done using passive filter. From Table 10, it is concluded that THD is reduced from 3.9% to 3.1% using passive filter. The 3rd and 5th harmonics were 0.5% and 0.3% without using filter and it is reduced to 0.2% and 0.2% by using passive filter.

Table 10
Harmonic analysis of three phase induction motor at blocked rotor load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	0.9	0.7
2.	5th	0.5	0.2
3.	$\mathbf{I_{THD}}$	**1.4**	**1.0**



(a) Without passive filter (b) With passive filter

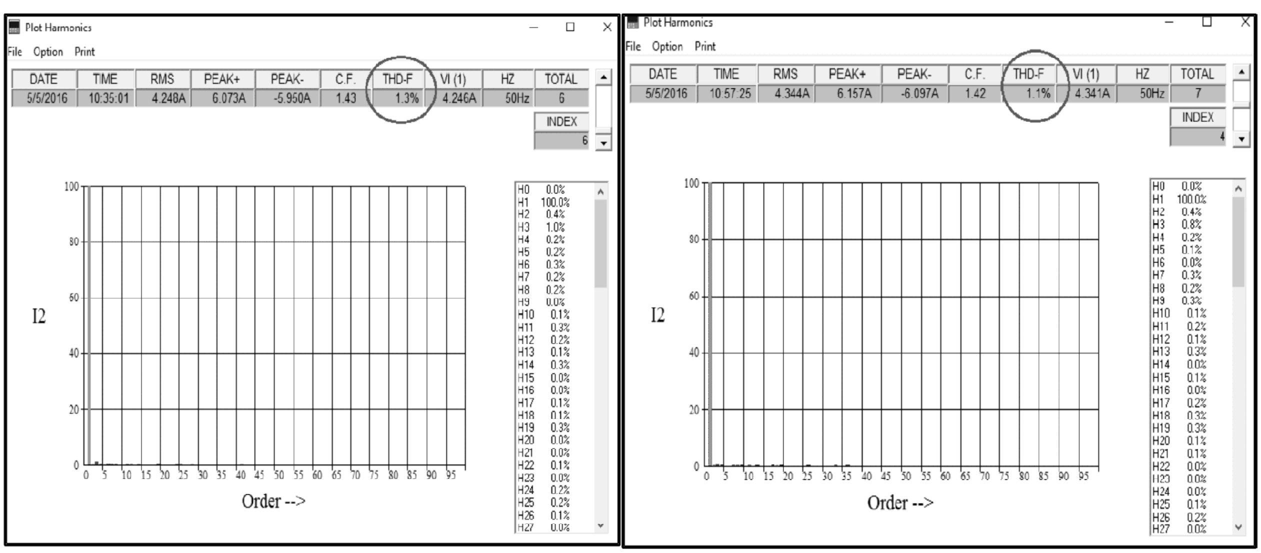
Figure 12: Harmonic analysis of three phase induction motor with and without passive filter

(B) For Current I-$_2$

For I_2, Harmonics mitigation is done using passive filter. From Table 11, it is concluded that THD is reduced from 1.3% to 1.1% using passive filter. The 3rd and 5th harmonics were 1.0% and 0.2% and found to be more predominant without using filter and it is reduced to 0.8% and 0.1% by using passive filter.

Table 11
Harmonic analysis of three phase induction motor at blocked rotor load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	1.0	0.8
2.	5th	0.2	0.1
3.	**I_{THD}**	**1.3**	**1.1**



(a) Without passive filter (b) With passive filter

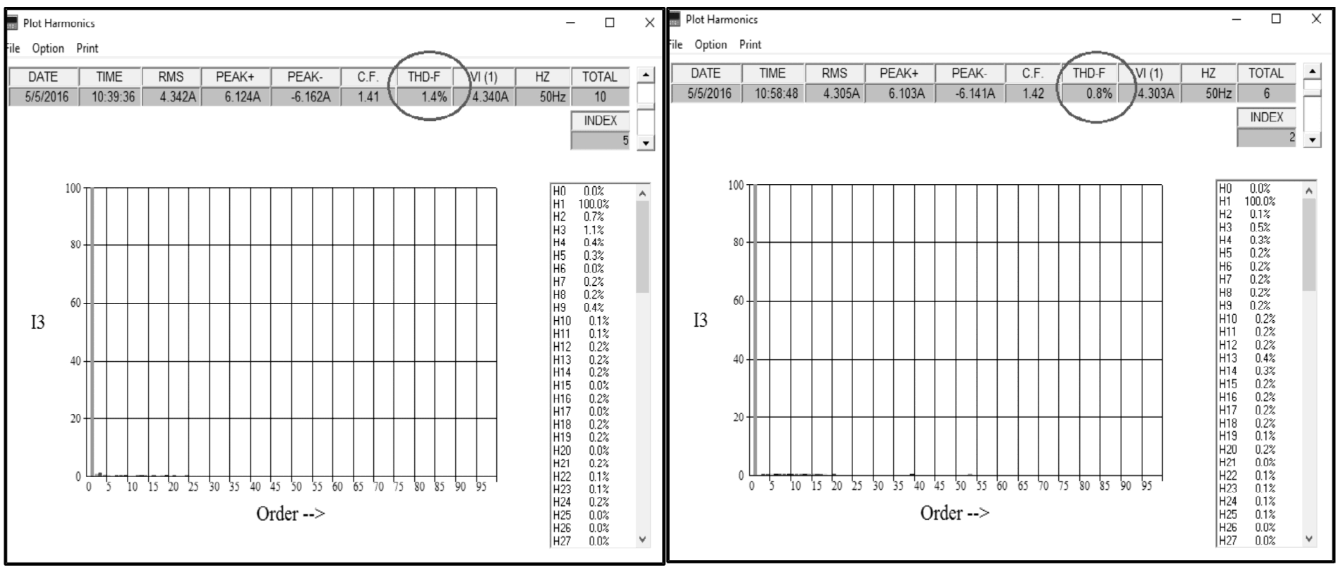
Figure13: Harmonic analysis of three phase induction motor with and without passive filter

(C) For Current I_3

For I_3, Harmonics mitigation is done using passive filter. From Table 12, it is concluded that THD is reduced from 3.9% to 3.1% using passive filter. The 3rd and 5th harmonics were 0.5% and 0.3% without using filter and it is reduced to 0.2% and 0.2% by using passive filter.

Table 12
Harmonic analysis of three phase induction motor at blocked rotor load condition

Sr. No	*Order of Harmonics*	*Current Harmonic Distortion without passive filter (%)*	*Current Harmonics distortion with Passive filter (%)*
1.	3rd	1.1	0.5
2.	5th	0.3	0.2
3.	**I_{THD}**	**1.4**	**0.8**



(a) Without passive filter (b) With passive filter

Figure 14: Harmonic analysis of three phase induction motor with and without passive filter

V. CONCLUSIONS

The current waveforms were analyzed using PQA for three phase induction motor at varying loads and it is observed that distortions in the current exists due to the use of these non linear loads. In this paper, Harmonic analysis is done for the induction motor with the help of power quality analyzer and 3rd and 5th harmonics are found to be more predominent so passive filter is designed accordingly. Mitigation of harmonics is done with the pasive filter and 3rd and 5th harmonics and the overall THD are reduced.

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