The Effect of Supply Distortion on the Performance of Three Phase Induction Motor

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***Abstract*- In power systems, induction motors are the largest component of the load and they are widely used in commercial, household and industrial applications. Once the power system is contaminated with harmonics, the operational characteristics of induction motors will be affected. This paper deals with the effect of supply distortion on performance of 3-Φ induction motor. This has been analyzed using PSCAD. The study involves the modeling of induction motor in three different conditions such as normal (negligible harmonics), with harmonics and with a builtinshunt active power filter. All the above three models are developed in PSCAD and the performance of induction motor has been analyzed. To validate the model developed, experiments are also conducted on a 3-Φ induction motor. The results show that, supply distortion or harmonics considerably reduces the efficiency of the induction motor. Further, introduction of a proper active power filter significantly improves the overall performance of induction motor.**

Keywords: Harmonics, PSCAD, IHD, THD and Active Filter.

I. INTRODUCTION

The electrical power system has been increasing in complexity at a rapid rate in the last few decades. Modern power electronic converters generate a wide spectrum of harmonic components, which deteriorate the quality of the delivered energy, increase the energy losses and further decreasing the reliability of the power system. In some cases, large converter system generates not only characteristic harmonics but also considerable amount of non-characteristic harmonics, which may strongly deteriorate the quality of power supply [1].

The generation of harmonics in power system is primarily due to the presence of non-linear elements and operation of the system in the non-linear operating range of equipment. Some of the main sources of harmonics in a power system are power converters, static VAr compensators, arc furnace loads etc [2]. The presence of harmonics in a power system is of major concern to the system utility. Due to the non-linear nature of power system elements, some amount of harmonics is always present in a power system.

Nonlinear loads create harmonics by drawing current in abrupt short pulses rather than in a smooth sinusoidal manner[3]. The major issues associated with the supply of harmonics to nonlinear loads are severe overheating and insulation damage. Increased operating temperature of induction motors; degrade the insulation material of its windings. If this heating were continued to the point at which the insulation fails, a partial or complete flashover may occur. One solution for power quality problem is to install active filters in the power system network. Ultimately, this would ensure a polluted free system with increased reliability and quality[4] [5].

In a power system, induction motors are the largest component of the load and they are widely used in commercial, household and industrial applications. Once the power system is contaminated with harmonics, the operation characteristics of induction motors will be affected [6].

In this paper the harmonics based performance of 3-Φ induction motor has been analysed using PSCAD. It involves the modeling of induction motor in three different conditions such as normal (negligible harmonics), with harmonics and with a built in shunt active power filter. All the three models are developed in PSCAD and the performance including Total Harmonic Distortion (THD) has been analysed.

II. RELATED DEFINITIONS AND CLASSIFICATION OF HARMONICS

It is well-known that power system nonsinusoidal voltage and current waves can be formed by a number of sources in the power network. Theoretically, any nonsinusoidal periodical waveform can be transformed into a different order harmonics source by Fourier analysis. Therefore, the nonsinusoidal voltage and current waves can be expressed as:

$$v(t) = \sqrt{2}[V_1 \sin \omega_0 t + \sum_{k=2}^{\infty} V_k \sin(k\omega_0 t + \varphi_k)] \quad \text{…. (1)}$$

$$i(t) = \sqrt{2}[I_1 \sin \omega_0 t + \sum_{k=2}^{\infty} I_k \sin(k\omega_0 t + \varphi_k)] \quad \text{…. (2)}$$

V_1, $I_1$are the fundamental voltage and current,

V_k, I_k are the k^{th}order harmonic voltage and current,Φ_k and θ_k are the phase angles of the k^{th}order harmonic voltage and current, and$\omega_o$is the radian frequency of the fundamental wave.

When anonsinusoidal voltage is supplied to a three phase induction motor, the motor rotor has a slip S corresponding to the fundamental and various harmonics slip $S_k$corresponding to the various k^{th}harmonics, and it can be expressed as

$$S_k = \frac{kN_s + (1-S)\,N_s}{kN_s} = \frac{k+(1-s)}{k} \quad \text{.... (3)}$$

According to the Magneto Motive Force (MMF) rotating direction, the 4th, 7th,…, [3n+l], n = 1, 2,…., order harmonics (positive-sequence harmonics) contribute MMF and torque in the positive (forward) direction; the 2nd, 5th,…., [3n+2], n = 0, 1, 2, …., order harmonics (negative sequence harmonics) provide counter MMF and torque; and the 3rd, 6th, ….,[3n],n = 1, 2, ..., order harmonics (zero-sequence harmonics) do not contribute any rotating MMF and torque. Although the positive sequence harmonics would add a boost to the positive sequence (forward) torque and thus be beneficial, the heating effects of the harmonics counteract the benefit of the positive sequence torque [6].

According to the definition of IEEE-519[7],the amount of voltage distortion is measured by the Total Voltage Harmonics Distortion Factor (THD_v) as:

$$THD_v\,(\%) = \sqrt{\frac{\text{Sum of squares of amplitudes of all harmonics voltages}}{\text{Square of amplitude of fundamental voltage}}}$$

$$= \frac{\sqrt{\sum_{k=2}^{\infty} V_k^2}}{V_1} * 100\,\%$$

III. MODELLING OF INDUCTION MOTOR WITH ACTIVE FILTER

In the present work 3- ϕinduction motor has been modeled in PSCAD. For this purpose a 5HP, 415V, 50Hz, 3- ϕ, 1440 RPM, Squirrel Cage induction motor is considered.

In order to study the effect of harmonics on the performance of induction motor, simulations were carried out with harmonic injection of 5%, 10% and 15% of rated current of induction motor. Further built in active power filter model based on instantaneous p-q theory with hysteresis current control method is adapted to the network, to improve the quality of power supply and performance of induction motor.

3.1 Harmonics Current Injection

Harmonics can be simulated in PSCAD by either building models of non-linear devices or by injecting the appropriate harmonic currents into a bus. The approach used in this paper is injecting currents into a bus.

3.2 Hysteresis current controller

A controlled current inverter is required to generate the compensating current. Hysteresis current\control is a method of controlling a voltage source inverter so that an output current is generated which follows a reference current waveform. This method controls the switches in an inverter asynchronously to ramp the current through an inductor up and down so that it tracks a reference current signal. Hysteresis current control is the easiest control method to implement[8].

Fig.1 gives the PSCAD model of 3-Φ induction motor with harmonic injection block and an active filter.

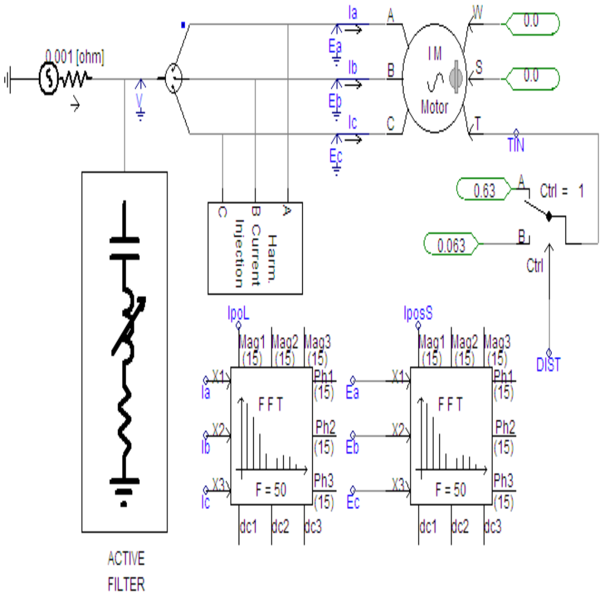

Fig.1 Model of a 3-Φ induction motor with Harmonic Injection block and an Active Filter

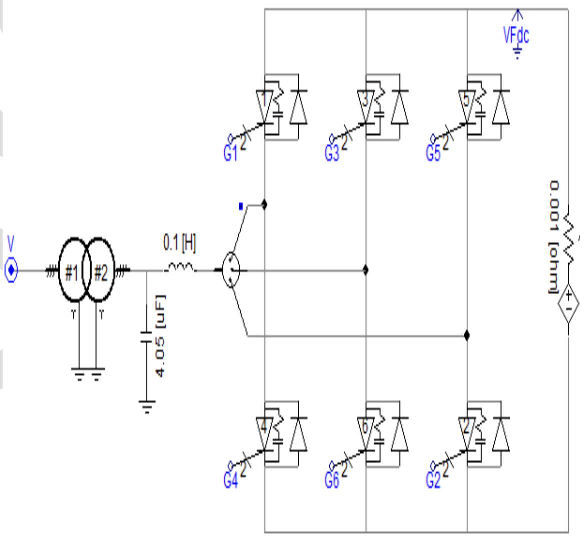

Fig.2 Simplified active filter in parallel configuration

Fig.2 gives the simplified model of active filter in parallel configuration. A DC source has been put in the place of DC capacitor, it has simplified a control system of active filter.

IV. RESULTS AND DISCUSSIONS

Simulations were carried out in three stages. In the first stage, induction motor mentioned above has been modeled in PSCAD without harmonics (normal operating condition). Model developed in the second stage involves harmonic injection of different magnitudes. In the third stage, a built in active filter has been incorporated in the model.

a. Under Normal Condition

The graphs recorded in PSCAD for Real and Reactive power, Line Currents, Line Voltages, Speed and Torque (Mechanical and Electrical) of theinduction motor are shown in Fig. 3 (a) to 3 (e) respectively.

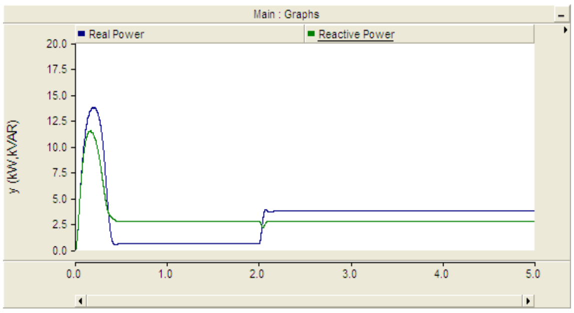

Fig.3 (a) Plot of Real and Reactive Power of the Induction Motor

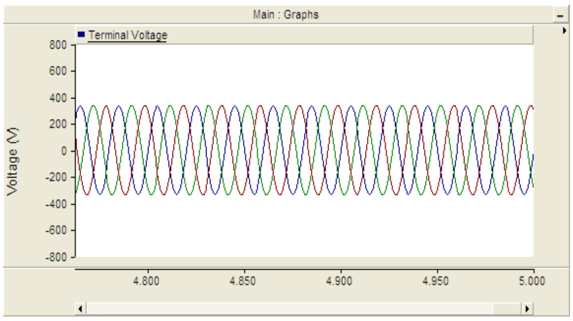

Fig.3 (b) Plot of Line Voltages

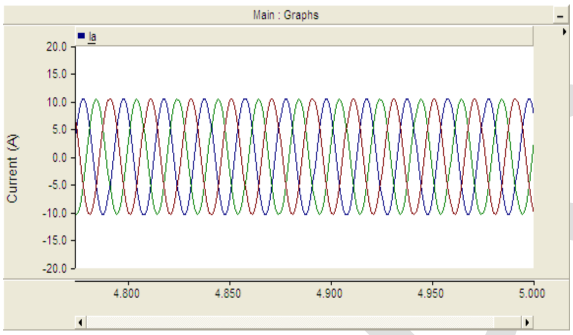

Fig.3 (c) Plot of Line Currents

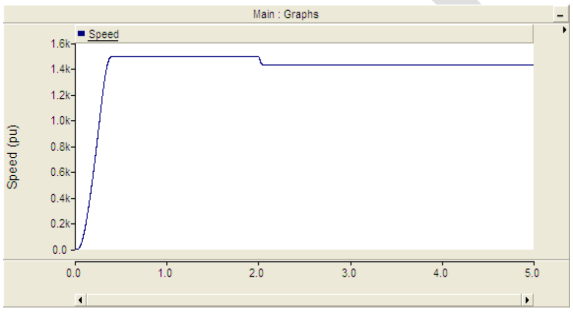

Fig.3 (d) Plot of Speed

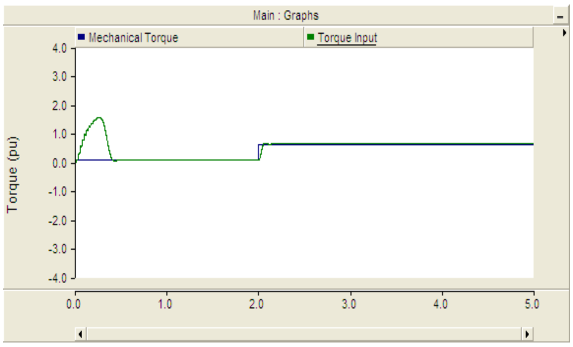

Fig.3 (e) Plot of Mechanical and Input Torque

Table.1 Results Obtained Under Normal Condition

SI NO.	Voltage in Volts	Current in Amps	Real Power in kW	% Efficiency
1	415	5.2	1.3	75.0
2	415	5.36	1.57	78.0
3	415	5.5	1.84	80.2
4	415	5.78	2.17	83.0
5	415	6.69	3.14	85.9
6	415	7.3	3.73	88.8

To validate the model developed, experiments are also conducted on a 5HP, 415V, 50Hz, 3-Φ, 1440 RPM, Squirrel Cage induction motor. Table2 gives the results obtained through the experiment.

Table 2 Results Obtained Through Experiment

SI NO.	Voltage in Volts	Current in Amps	Real Power in kW	% Efficiency
1	410	5.0	1.64	63.7
2	410	5.2	1.76	71.8
3	408	5.85	2.48	75.4
4	408	6.4	2.84	82.3
5	408	7.3	3.84	84.5

For better comparison model and experimental results are plotted as shown in Fig.4

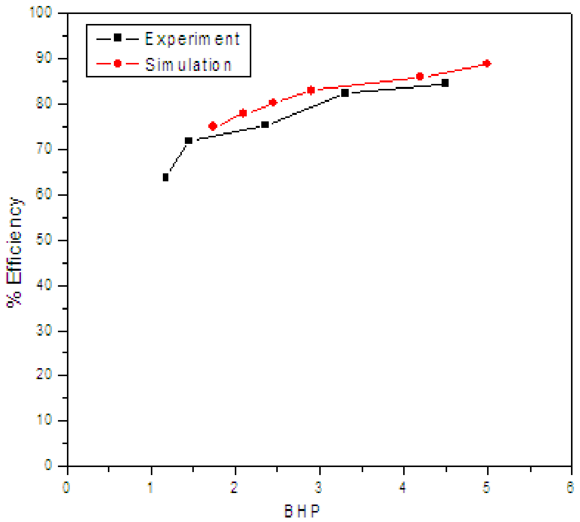

Fig.4 Variation of Efficiency with respect to BHP

From the above simulation, necessary performance calculation are made and given in Table 1.

From Fig.4 it can be observed that the results obtained by the present model are in goodagreement (within 10%) with Experimental results, which validate the present model developed in PSCAD.

b. With Harmonic Injection

Fig. 5(a) to 5(e) shows the plots obtained in simulations for the case of harmonic injection of 15% and Fig.5(f) indicate plot of Individual Harmonic Distortion(IHD) and THD with 15% harmonic injection.
Tables 3 to 5 tabulate the results obtained in PSCAD for the harmonic injection of 5%, 10% and 15% respectively.

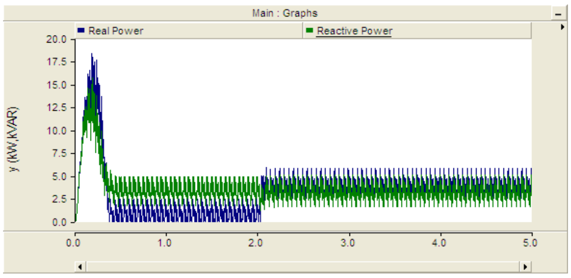

Fig.5 (a) Plot of Real and Reactive Power of the Induction Motor

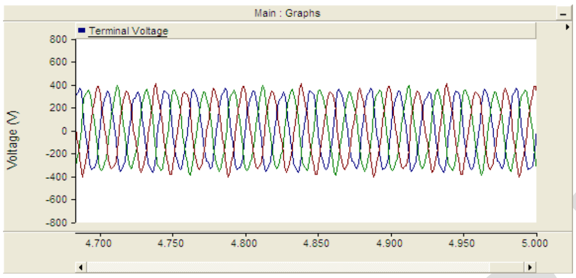

Fig.5 (b) Plot of Line Voltages

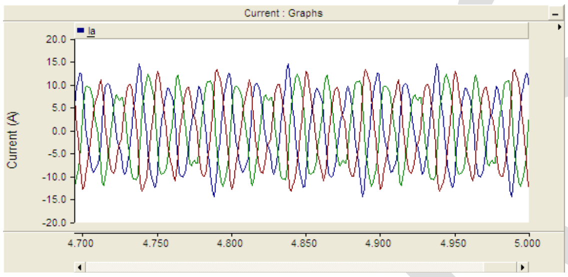

Fig.5 (c) Plot of Line Currents

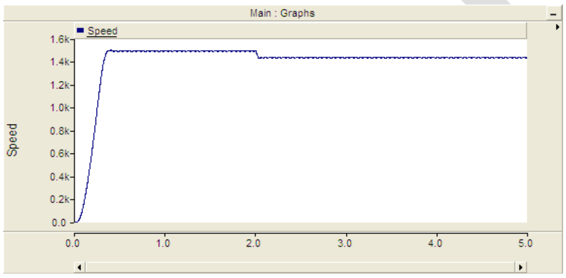

Fig.5 (d) Plot of Speed

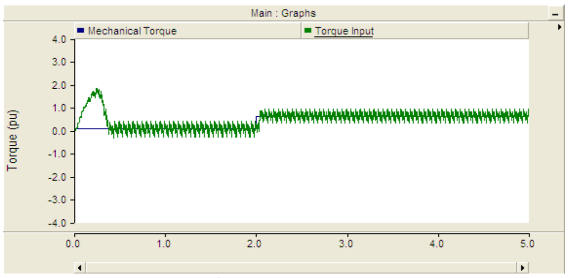

Fig.5 (e) Plot of Mechanical and Input Torque

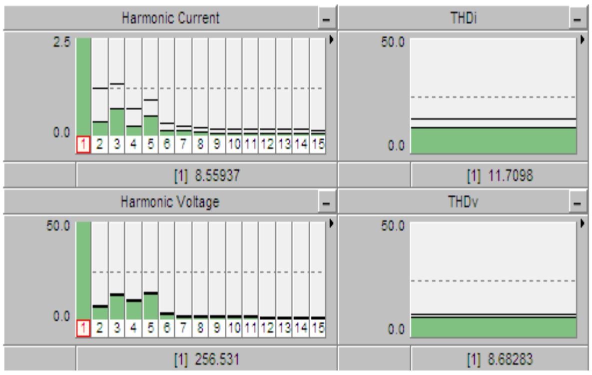

Fig.5 (f) Plot of IHD and THD

Table.3 With Harmonic Injection of 5% of Rated Current of 5 HP Induction Motor

SI. NO.	Voltage in Volts	Current in Amps	Output Power in kW	% Efficiency
1	422.3	5.64	1.24	71.6
2	422.3	5.76	1.52	72.2
3	422.3	5.91	1.78	73.5
4	422.3	6.14	2.10	74.2
5	422.3	7.02	3.06	79.5
6	422.3	7.67	3.65	82.4

Table.4 With Harmonic Injection of 10% of Rated Current of 5 HP Induction Motor

SI. NO.	Voltage in Volts	Current in Amps	Output Power in kW	% Efficiency
1	437	6.45	1.09	57.3
2	437	6.54	1.36	58.5
3	437	6.67	1.63	59.8
4	437	6.87	1.96	61.8
5	437	7.66	2.91	67.8
6	437	8.24	3.5	71.0

Table.5 With Harmonic Injection of 15% of Rated Current of 5 HP Induction Motor

SI. NO.	Voltage in Volts	Current in Amps	Output Power in kW	% Efficiency
1	445	6.89	1.0	50.9
2	445	6.97	1.27	52.5
3	445	7.09	1.54	54.2
4	445	7.27	1.87	55.6
5	445	8.0	2.83	62.0
6	445	8.56	3.43	65.8

From the Fig. 5(b) and 5(c), it is observed that, the voltage and current waveforms are no longer sinusoidal and highly distorted, due to the presence of harmonics in the system.

From the Table 3 to 5 for the harmonic injection of 5%, 10% and 15% of rated current of 5 HP induction motor. It is observe that there is decrease in the efficiency from 4.53% to 32.1% and 7.2% to 25.9% under light and full load condition.

Further it is also observed that under light load the effect of harmonics is more compare to full load and it is more than IEC standards.

c. Simulation with Active Filter

Fig. 6 indicate plot of IHD and THD for the case of harmonic injection of 15% with active filter.

With the introduction of active power filter the rise in the current and voltage values get limited with respect to normal operating condition.

From the Table 6 to 8 for the harmonic injection of 5% to 15% of rated current of 5 HP induction motor with active filter, it is observed that, there is increasein input current about 1.5% to 3.6%. Further there is increase in the input voltage of about 0.1% to 0.5%

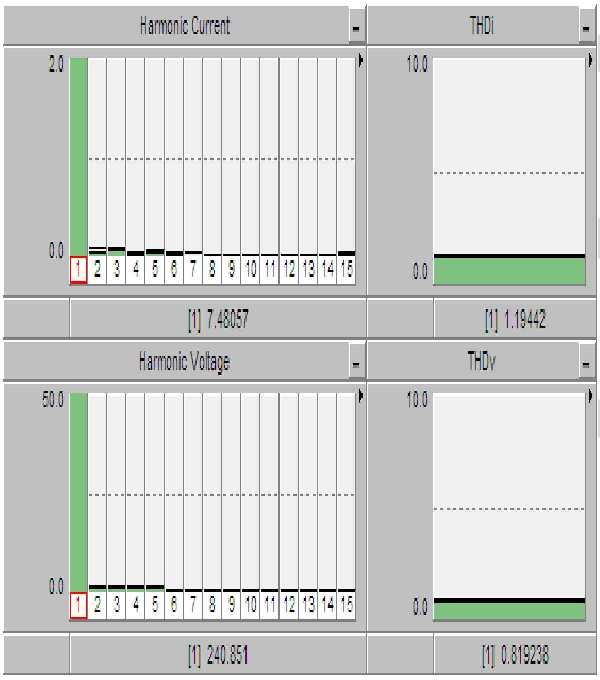

Fig. 6Plot of IHD and THD

Table.6 Harmonic Injection of 5% of rated current of 5 HP Induction Motor with Active Filter

SI. NO.	Voltage in Volts	Current in Amps	Output Power in kW	% Efficiency
1	415.5	5.31	1.29	75.0
2	415.5	5.43	1.56	78.3
3	415.5	5.59	1.89	81.0
4	415.5	5.83	2.4	81.7
5	415.5	6.74	3.13	85.0
6	415.5	7.42	3.72	87.0

Table.7 Harmonic Injection of 10% of rated current of 5 HP Induction Motor with Active Filter

SI. NO.	Voltage in Volts	Current in Amps	Output Power in kW	% Efficiency
1	416.6	5.36	1.28	75.0
2	416.6	5.49	1.55	78.3
3	416.6	5.64	1.82	78.5
4	416.6	5.88	2.15	80.4
5	416.6	6.79	3.12	83.8
6	416.6	7.46	3.71	86.2

Table.8 Harmonic Injection of 15% of rated current of 5 HP Induction Motor with Active Filter

SI. NO.	Voltage in Volts	Current in Amps	Output Power in kW	% Efficiency
1	417.2	5.39	1.28	74.7
2	417.2	5.51	1.55	77.8
3	417.2	5.67	1.82	78.0
4	417.2	5.9	2.15	80.0
5	417.2	6.81	3.11	84.3
6	417.2	7.48	3.7	85.6

and these values are negligible in the practical system. This shows the role of active filter in improving the performance of induction motor.

V. COMPARISON OF EFFICIENCY FOR WITH AND WITHOUT FILTER

From Fig.7 and Table.9, it is observe that by adopting Active Filter under harmonic injection of 5% to 15%, there is increase in the efficiency of induction motor by 4.13% to 22.3% compare to normal operating condition.

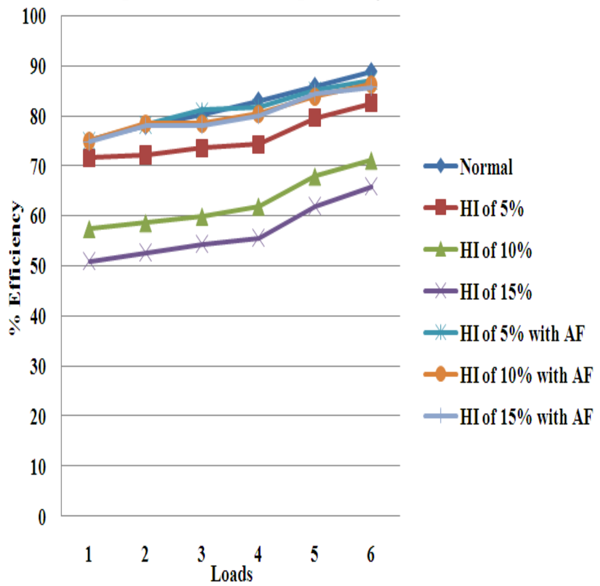

Fig.7 Variation of Efficiency with respect to load for 5HP motor with Harmonic Injection of 5%, 10% and 15% for with and without Filter.

VI. CONCLUSIONS

The work emphases on the importance of active power filter in improving the overall performance of induction motor.

- The results obtained for 5 HP induction motor in PSCAD and experimental are in good agreement (within 10%) which shows the validity of the model developed in PSCAD.
- With the increase in percentage harmonic voltage and current the performance of induction motor decreases.
- It can be concluded that harmonics causes extra loss to utilities and extra electrical charges to consumers. Due to increase in percentage harmonic voltage to the three phase inductionmotor causes rotor vibration. The vibration of the rotor can increase friction losses of the bearings and reduce the lifespan of the bearings, thus largely increase the probability of mechanical failure.
- Increase in percentage harmonic current in the three phase induction motor causes overheating, resulting in rise in the temperature. The rise in the temperature causes development of hot spot leading to failure of insulation. This failure may cause partial and complete flashover. In other words the failure of insulation also reduces the life span of induction motor.
- The present work helps in understanding the effectiveness and/or role of Active Filter to improve the power quality of supply distortion which inturn reduces the losses and thereby increasing the overall performance of the induction motor.

Table.9 Efficiency of Induction Motor under various percentages of Harmonic Injection and loads for with and without filter

SI NO.	Normal	Harmonic Injection of 5%	Harmonic Injection of 10%	Harmonic Injection of 15%	Harmonic Injection of 5% with Active Filter	Harmonic Injection of 10% with Active Filter	Harmonic Injection of 15% with Active Filter
1	75.0	71.6	57.3	50.9	75.0	75.0	74.7
2	78.0	72.2	58.5	52.5	78.3	78.3	77.8
3	80.2	73.5	59.8	54.2	81.0	78.5	78.0
4	83.0	74.2	61.8	55.6	81.7	80.4	80.0
5	85.9	79.5	67.8	62.0	85.0	83.8	84.3
6	88.8	82.4	71.0	65.8	87.0	86.2	85.6

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