Effect of Harmonics on the Performance Characteristics of Three Phase Squirrel Cage Induction Motor

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Abstract- Harmonics have existed in power systems for many years. These harmonic currents are injected into the network by nonlinear loads such as power electronic equipment, arc furnaces, saturating inductances etc. Unbalanced voltages or harmonics in the voltage source could result in problems like excessive losses, harmonic volt drops over-voltages, mechanical oscillations, so that the supply voltage to the motor is no longer sinusoidal. Detecting these abnormal conditions in the machine is of great importance in the interaction of the electrical machine. PWM technique is proven to be an effective way of controlling speed of induction motor. This paper presents the Matlab/Simulink model of the PWM operation, DC/AC converter and a three phase Squirrel Cage Induction motor. By changing the frequency of the motor speed can be reliably controlled and this is done by DC/AC converter which results in adjustable voltage and frequency AC power. We also investigated the effect of harmonics on the motor performance and the motor behavior in low power quality condition. Some of most important issues of this phenomena are Efficiency reduction, increase in motors temperature and oscillations in steady state torque.

Keywords- *Three phase Induction motor, Harmonics, Pulse-width modulated inverter.*

I. INTRODUCTION

The application of nonlinear loads as a result of power electronic development is growing very fast. In general view, the shape of network voltage can't be imagined sinusoidal and motor manufacturers have to consider non-sinusoidal conditions in their designs. The harmonics of network voltage effect on operation of all electrical equipment like relays, that are the guards of power system, measurement equipment, and electric motors, that are the wheels of industries. In fact, all of these equipment have been designed to work in normal conditions, but in real networks the power is non-sinusoidal that reduces the motor efficiency and their lifetime [1]. Temperature rise of machines is the most effective parameter that decreases the age of insulation [2], and consequently the lifetime of the machine that depend on the health of its insulation. High temperature of the insulation declines its age exponentially according to the Arrehnius equation [3]. Many parameters like different load cycling, switching, working in hot weather, harmonics and unbalances are major reasons in temperature rise of the motors. The motor losses consist of mechanical and electrical losses. Mechanical losses that caused by friction and windage are not affected by harmonics [4], but electrical losses that consist of iron winding and stray load losses depend on order and magnitude of harmonics. Hysteresis loss and eddy current loss that take place in the iron vary with the square of the air-gap voltage. The harmonic currents are proportional to the magnitude of voltage harmonics, i.e. the stray load loss and winding loss vary with the square of the voltage harmonic.

II. FACTORS CONTRIBUTING HARMONICS

Various industrial loads including static converters (such as electric furnace, induction heating devices and switching power supply) inject current harmonics in power systems. Generally power electronic devices such as switching sources and converters are most important sources of harmonic generation. Converters usually generate harmonics from nth level in AC side.

$$n = kn_p \pm 1$$

Where:

k is a constant

and n_p is the number of converter pulses.

This phenomena lead to distortion in voltage like as iron saturation in over loaded distribution transformers. Induction motor under perfect sinusoidal supply condition generate little amount of current harmonics. Because of its coils structure and non linear behavior of iron core. Most important consequent of this phenomenon is efficiency decrease. Installation of capacitor placement in distribution systems for power factor correction and series reactor in transmission lines for decrease in short circuit current are not direct causes of harmonic generating but because of probability of resonance generation can intense and magnify existed harmonics.

III. HARMONIC EFFECTS ON INDUCTION MOTORS

Voltage harmonic because of heat and oscillations produce in rotor cause most important damage to induction motor.

Rotors oscillations are because of torque ripples and these ripples emerge from positive and negative ordinary harmonics. Rotors oscillations can increase friction losses of bearings. Since motors temperature in present of any harmonic would be higher than normal state and this will damage to bearings and stator coil and consequently motors life will be increased. Amount of this decrease is dependent to motors class. Fig.1 shows relation between motors life and its temperature in E,B and F classes. It is seen from Fig.1 that 8 degree increase in motors temperature in class E and 10 degree in class B and 12 degree in class F lead to motors life reduction to half. Preventing this affair is required derating on motors. This prohibit from motors temperature increase in non sinusoidal supply condition. Equation below determine amount of decrease in motors nominal values for prevent from temperature increase

$$Derating\ \ factor = 1-(\frac{T_{1+K}-T_1}{T_1})*100\%$$

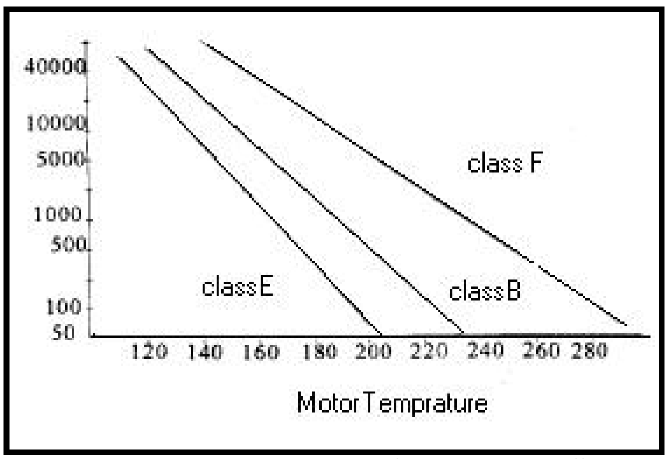

Fig 1. Induction motors temperature and its life relation in three different classes

Higher VDF (Voltage Distortion Factor) stands for more harmonics existence in supply voltage and cause lower efficiency. Also lower order harmonics lead to lower efficiency. Increase of VDF decrease motors power factor and lower order harmonics have more profound effect on power factor. Input current in low order harmonics is higher and with VDF increase in some harmonic order increase. We must know that under 5th order harmonics effects on motor are very greater than higher order harmonics. For example in VDF=10% the motors temperature increase for 2nd , 3rd , 4th and 5th order harmonics are 23%, 6%, 14% and 8% respectively. It is obvious with increase in harmonics order their effect is reduced on motors operation.

$$\%\Delta T = \frac{T_K - T_1}{T_1}*100\%$$

IV. HARMONIC ANALYSIS

Because of the destructive effects of the harmonics like torque pulsation, acoustic noise and increased losses a wide variety of the research have been done to minimize the harmonics in the voltage supply [4-6]. In our work three major harmonics namely, 3rd, 5th, and 7th harmonics are introduced to the model. The machine has been supplied with the rated voltage and the harmonics are injected in the voltage source. The applied voltage can be written as:

$$V(t) = V_1 \sin(2\pi f t) + \sum_{k=3,5,7} V_k \sin(2\pi k f t + \theta_k)$$

It is shown in [7] that the current in the stator windings are as follows:

$$I_k(t) = \frac{V_k(t)}{\sqrt{(R_{eq}^2 + X_{eq}^2)}} \qquad k = 1,3,5,7$$

In which *Req* and *Xeq* are stator equivalent resistance and reactance respectively. Based on the above current equation it is expected that the harmonics with the same frequency but different amplitude would be present in the stator currents.

ODD HARMONICS

All the odd harmonics (third, fifth, seventh, ninth, etc.) are present in the phase voltage to some extent and need to be dealt with in the design of ac machines.

5th Harmonic

In this case the 5th harmonic is injected into the voltage Sources. As the main frequency of the voltage source is 50Hz the harmonic frequency is 250Hz. According to the standards the magnitude of the harmonics should be less than 5% of the main frequency magnitude. The following results are obtained when 5th harmonic is injected.

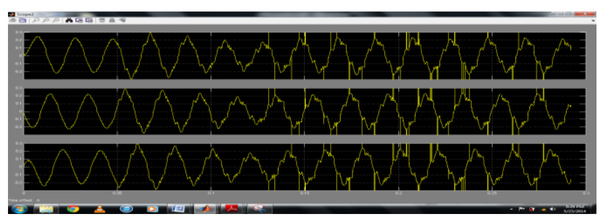

Fig 2.Three phase supply current

Fig 3.Speed vs. time

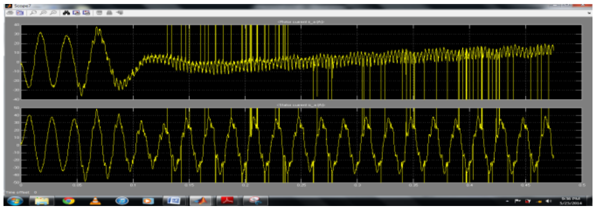
Fig 4.Rotor current & stator current vs. time

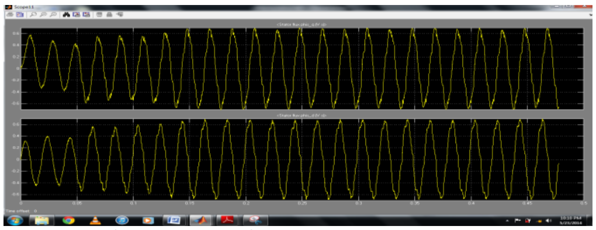
Fig 5.Stator flux_q & stator flux_d

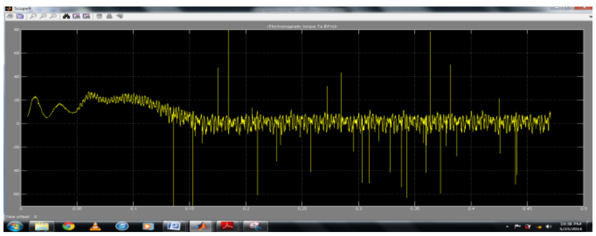
Fig 6.Electromagnetic torque vs. time

7th Harmonic

In this case the 7th harmonic is injected into the voltage sources. As the main frequency of the voltage source is 50Hz the harmonic frequency is 350Hz. The following results are obtained when 7^{th} harmonic is injected

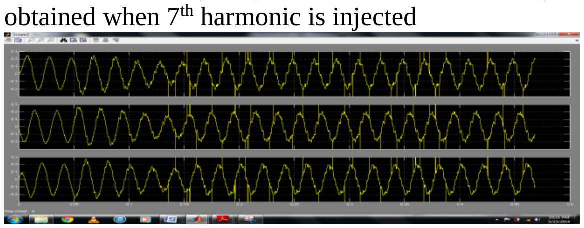
Fig 7.Three phase supply current

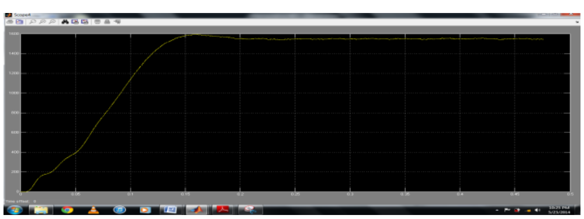
Fig 8.Speed vs. time

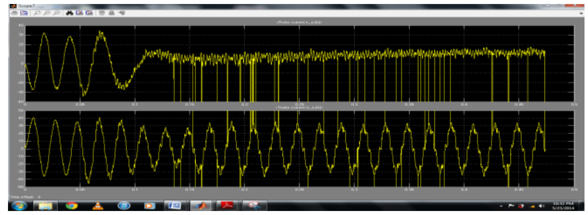
Fig 9.Rotor current & stator current vs. time

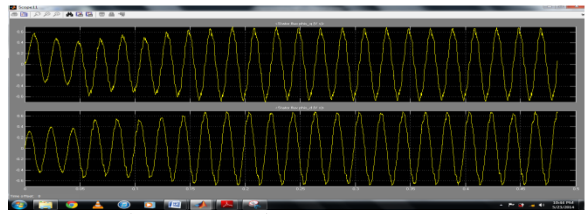
Fig 10.Stator flux_q & stator flux_d

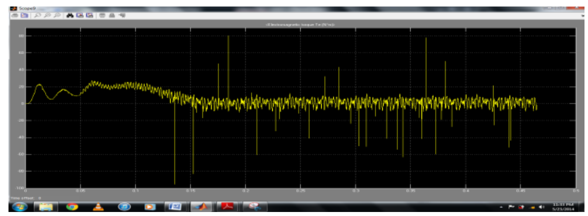
Fig 11.Electromagnetic torque vs. time

TRIPLEN HARMONIC

In Y- connected, the third-harmonic voltage between any two terminals will be zero. This result applies not only to third-harmonic components but also to any multiple of a third-harmonic component (such as the 9^{th} harmonic). Such special harmonic frequencies are called Triplen harmonics. A third harmonic is added to the sine wave to make the waveform more flat topped. Adding a third harmonic does not constitute a problem as the third harmonic and multiples thereby will not been seen in the line-to-line voltage. Due to the symmetry of the waveform **(f(t)=-f (t+T/2)** where T is the period of the supply sine waveform, even ordered harmonics cannot exist. Let the R phase supply voltage be given by the expression

$$V_R=V_{1m}\sin(w_1t+\Phi_1)+V_{3m}(3w_1t+\Phi_3)+V_{5m}\sin(5w_1t+\Phi_5)+V_{7m}\sin(7w_1t+\Phi_7)+\ldots$$

Being a balanced three phase supply, we know that the waveforms of V_Y and V_B are 120◦ and 240◦ shifted from V_R respectively. If a waveform is shifted by φ degrees, its harmonics are shifted by n_φ degrees, where n is the order of the harmonic. Thus the expressions for V_Y and V_B would be

$$V_Y= V_{1m}\sin(w_1t+\Phi_1-2\pi/3)+V_{3m}(3w_1t+\Phi_3-3.2\pi/3)+V_{5m}\sin(5w_1t+\Phi_5-5.\ 2\pi/3)+V_{7m}\sin(7w_1t+\Phi_7-7.\ 2\pi/3)+\ldots\ldots.$$

$$V_B=V_{1m}\sin(w_1t+\Phi_1-4\pi/3)+V_{3m}(3w_1t+\Phi_3-3.4\pi/3) + V_{5m}\sin(5w_1t+\Phi_5-5.4\pi/3) + V_{7m}\sin(7w_1t+\Phi_7-7.\ 4\pi/3)+\ldots\ldots$$

If we consider the third harmonic components of the three phase waveforms, and if $V_{x3}(t)$ is the third harmonic of phase x, we can see that

$$V_{R3}=V_{3m}\sin(3w_1t+\Phi_3)$$
$$V_{Y3}=V_{3m}\sin(3w_1t+\Phi_3)$$
$$V_{B3}=V_{3m}\sin(3w_1t+\Phi_3)$$

Therefore, all the three third harmonics are in phase. In a STAR connected system with isolated neutral, these voltages cannot cause any current flow since all three terminals are equal in potential. If the neutral point is connected to some point, then current can flow through the neutral connection. Such a connection is however rare in induction machines. The machine is therefore an open circuit to third harmonics. In fact, one can see that any harmonic whose order is a multiple of three, i.e., the triplen harmonics, will face an identical situation. Since the machine is an open circuit to triplen harmonics in the excitation voltage, these do not have effect on the machine.

In this case the 3rd harmonic is injected into the voltage sources. As the main frequency of the voltage source is 50Hz the harmonic frequency is 150Hz. According to the standards the magnitude of the harmonics should be less than 5% of the main frequency magnitude. Triplen harmonics are zero-sequence harmonics that are multiples of third harmonic and they have no effect on torque pulsation. Following graphs are obtained

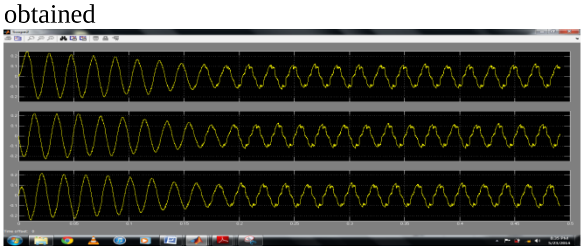

Fig 12.Three phase supply current

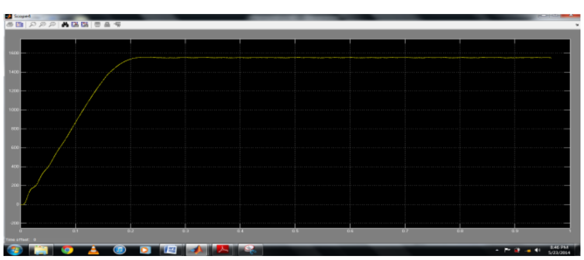

Fig 13.Speed v/s time

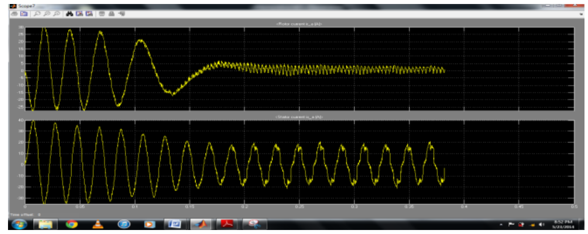

Fig 14.Rotor current & stator current v/s time

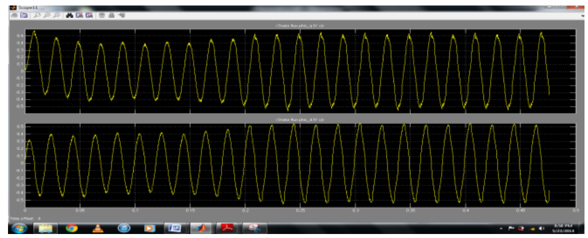

Fig 15.Stator flux_q & stator flux_d

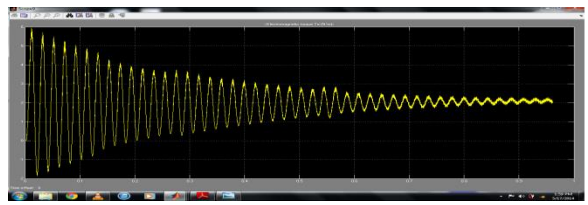

Fig 16.Electromagnetic torque vs. time

Description	THD(current)	THD(voltage)
PWM supply(no harmonic added) F=50hz	7.96	4.465
3rd harmonic inserted ,F=150hz	6.503	4.065
5th harmonic inserted , F=250hz	9.453	20.57
7th harmonic inserted , F=350hz	9.132	18.87

Table no.1

V. CONCLUSION

This study has investigated harmonic generator factors and their effects on induction motors performance and also the negative and positive effects of harmonics on the performance of three phase squirrel cage induction motor. The main conclusions from the study is that, harmonics in the voltage source can cause excessive losses, extra noise and pulsating torque.. These effects include efficiency reduction, generation of torque oscillations in steady state. Also these oscillations cause mutual effect of stator and rotor and lead to motors temperature increase. For preventing of excessive rise of motors temperature, motors should be derated. On the other hand triplen harmonic does not affect the motor performance because machine will act as a open circuit to the triplen harmonics. As it is shown in the Table 1 that on adding the 3rd harmonic in to the phase current will decrease the THD(total harmonic distortion) in current and voltage supply given to the asynchronous motor . The possibility of injecting third harmonic current components into the machine without producing pulsating torques enables the ability to reshape the machine's flux distribution. And also lower order harmonics have more weighty effect on the motor because Input current in low order harmonics is higher. Under 5th order harmonics effects on motor are very greater than higher order harmonics. So therefore with increase in harmonics order their effect is reduced on motors operation.

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