Induction Motors Behavior Under Non Sinusoidal Voltage Supply Condition and Assessment of its Damages in Iran Network

S. Jalilzadeh, H. Hosseinian, S. Galvani, F.Razavi

Abstract—**An induction motor behaviors in low power quality condition is presented in this paper. Simulations are done for both ideal supply and non proper supply conditions. In this paper, we use two case study including one 3hp (small range) motor and one 50hp (medium range) motor and effects of non ideal supply voltage on motors characteristics are studied. Efficiency reduction, increase in motors temperature and oscillations in steady state torque are some of most important issues of this phenomena. Considering the traditional derating on induction motors in such situations and motors efficiency reduction and other effects of non sinusoidal supply on induction motors, the harmfulness of this type of supply on Iran network (considering abundant usage of induction motors) has been calculated and the importance of preventing non sinusoidal supply is illustrated.**

Index Terms— **harmonic, induction motor, non sinusoidal, torque**

I. Introduction

Induction motors are commonly used in industry and sensitive to voltages harmonics and their operation and efficiency can be affected intensely their supplied power quality. Some oscillations in three phase induction motors torque appear on launch time which these oscillations damped in very short time. Although the torque amount can be negative in that time but average value remain positive because of motors stable operation. If we use from speed-torque curve for depict of motor behavior in steady state. In very applications these oscillations will not be appreciable and can be negligible. In non sinusoidal supply conditions the oscillations existing in transient state is not damped and survive to steady state (with small value). This paper is research about induction motors transient behavior on non ideal supply condition.

II. Harmonic Generator Factors

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.

$$n = kn_p \pm 1 \qquad (1)$$

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 phenomena 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 iin 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(2) determine amount of decrease in motors nominal values for prevent from temperature increase.

$$Derating \;\; factor = 1 - \left(\frac{T_{1+K} - T_1}{T_1}\right) * 100\% \qquad (2)$$

S.Jalilzadeh, H.Hosseinian and S.Galvani are with the department of electrical engineering, Zanjan University, Zanjan, Iran (corresponding author phone: 0098-261-4333766; e-mail: hadi.hosseinian@yahoo.com).

F. Razavi, is with department of electrical engineering, Amir kabir university of technology,Tehran, Iran.

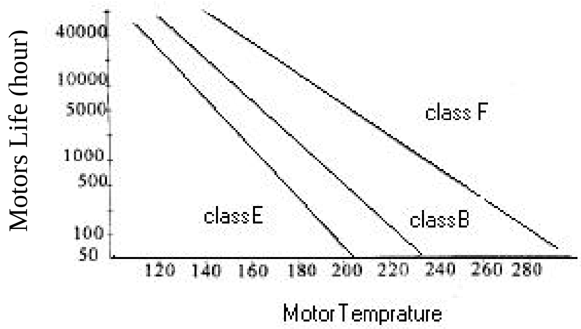

Fig. 1. Induction motors temperature and its life relation in three different classes

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.

$$\%\Delta T = \frac{T_K - T_1}{T_1} * 100\% \quad (3)$$

IV. Three Phase Induction Motor

Induction motors consist of one multi phase coil which distributed in stator evenly and other coil which has been short circuit in induction motors alternative current (AC) is applied to stator and the current is induced in rotor.[2]

We accept in this paper assumptions listed in below.

- Air gap in motor is even.
- Magnetic circuit is linear.
- Rotors and stators resistance are fix.
- Stator coil is distributed so generate sinusoidal MMF
- Some phenomena such as core losses and saturation and harmonics of MMF and resistors changes with temperature are neglected.

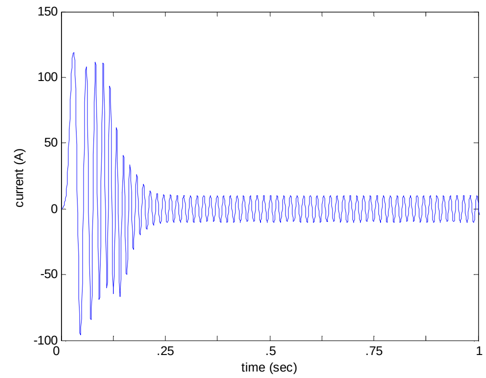

Fig. 2. Current of one phase of induction motor

Asynchronous machine has considered as two pole and Y connected.

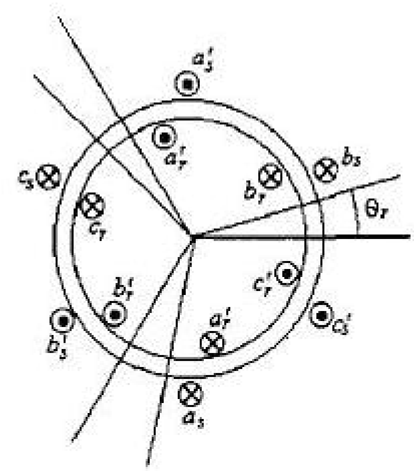

Fig. 3. Schematic image of three phase induction motor

Simulation of induction motors launch time has carried out on two type machines (small and medium size). Initially the voltage supply supposed symmetrical and exactly sinusoidal and for disturbed voltage supply the simulations has carried out. Supplied voltage waveform has VDF equal 10%. Results are shown for 3hp and 50hp motors in Fig.4 and Fig.5.

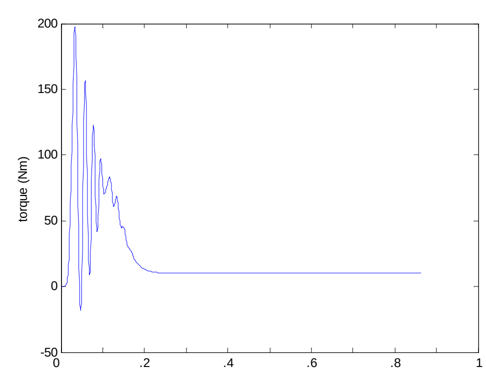

Fig. 4. 3hp induction motors torque under sinusoidal supply condition

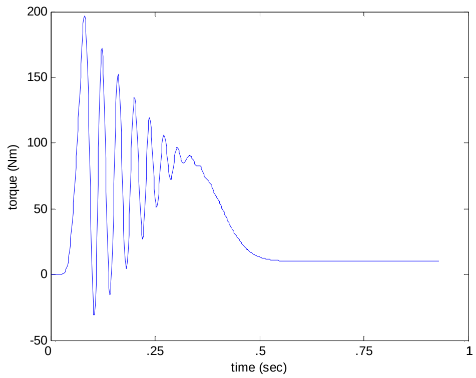

Fig. 5. 50hp induction motors torque under sinusoidal supply condition

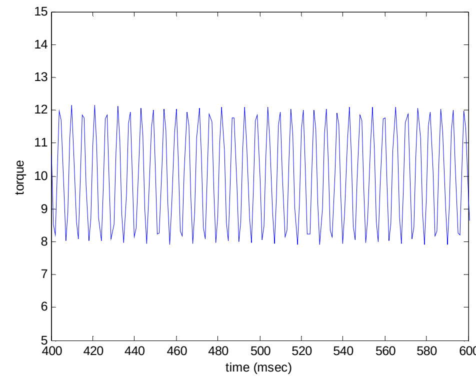

Fig.5. 3hp induction motors torques oscillations in steady state under non ideal supply condition

Results for simulation with harmonic included supply voltage have shown in Fig.6, Fig.7 and Fig.8. if we compare resulted torques in Fig.4 with Fig.6 and Fig.5 with Fig.7

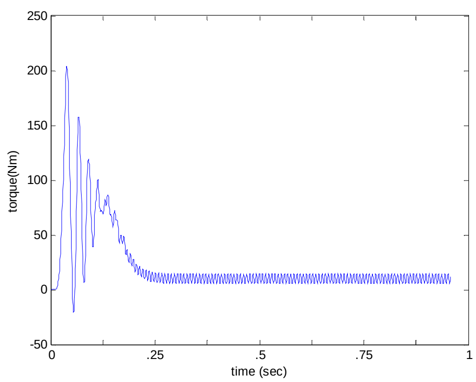

Fig. 6. 3hp induction motors torque under non ideal supply condition

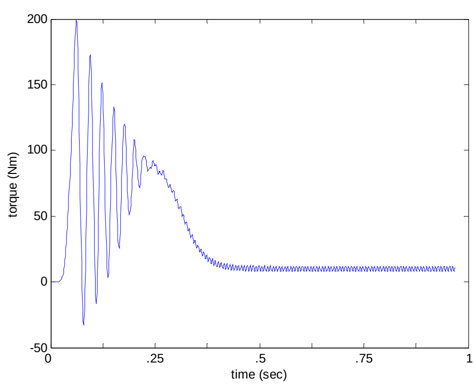

Fig. 7. 50hp induction motors torque under non ideal supply condition

The effect of non proper supply on motors torque barely will be illustrated. Oscillations of torque in 3hp and 50 hp motors in steady state have shown and have magnified in Fig.8 and Fig.9. The existence of this torque oscillations in motors in harmonic included supply condition lead to rotor exit from its axial location and bearings to rub and decrease their life and increase in motors temperature.

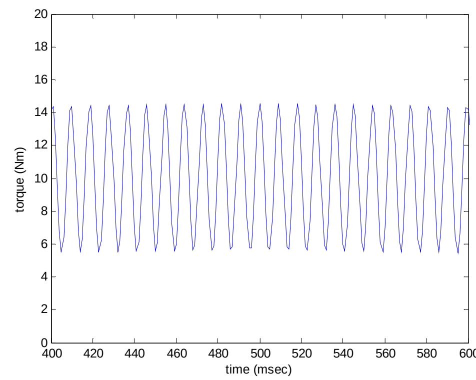

Fig.5. 50hp induction motors torque oscillations in steady state under non ideal supply condition

Efficiency reduction in motors means the losses increase. If the output of induction motor kept in nominal value, input power should be increased. In other word when induction motor is supplied with non sinusoidal voltage in nominal output power getting same work from motor we are forced to increase motors consumed power and this means consumers paid cost will be increased. With consider to experience of 700,000 induction motor in range 1hp to 5hp (average 3hp) in Iran network, redundant consumption of electric energy and cost of this phenomena which enforced to consumers has shown in table I. This calculation has performed based on VDF=10%. In ideal condition, motors efficiency has assumed 83% so average consumed power in motors achieved equal 2.69Kw (3*746/0.83).First column imply to existed harmonics order in supply voltage and load increase rate which has came in forth column is defined as(4).

$$LDIR = \frac{\eta_1}{\eta_{1+k}} \tag{4}$$

Where:

η_1 is the motors efficiency in sinusoidal supply condition and

η_{1+k} is the motors efficiency in harmonic included supply condition

TABLE I. ASSESSMENT OF DAMAGES CONSEQUENT FROM VARIOUS HARMONIC ORDERS EXISTENCE IN SMALL SIZE INDUCTION MOTORS SUPPLY VOLTAGE IN IRAN NETWORK

Order of existed harmonic in supply voltage	**Sum of installed induction motors capacity (KW)**	**Motors efficiency (%)**	**Load Increase Rate(LDIR)**	**Redundant consumed power in each year (KW)**	**Average of motors usage time in year (hour)**	**Redundant consumed electric energy in each year (Kwh)**	**Wasted cost for redundant consumed energy in year ($)**
1	1883700	83.15	1	0	2500	0	0
1+2	1883700	79.67	1.0437	82317.7	2500	205794250	10289712
1+3	1883700	82.04	1.0135	25429.9	2500	63574750	3178737
1+4	1883700	81.13	1.0248	46715.7	2500	116789250	5839462
1+5	1883700	81.40	1.0214	40311.2	2500	100778000	5038875
1+6	1883700	82.17	1.0119	22416.0	2500	56040000	2802000
1+7	1883700	81.95	1.0146	27502.0	2500	68755000	3437750
1+8	1883700	82.07	1.0132	24864.8	2500	62162000	3108100
1+9	1883700	82.46	1.0084	15823.0	2500	39557500	1977875
1+10	1883700	82.33	1.0100	18837.0	2500	47092500	2354625

These values of efficiency in present of various harmonic orders were achieved from [3]. For calculation of amount of damages, cost of electric energy in world markets (50$ for one MW of electric energy) is considered.

V. CONCLUSION

In this paper the harmonic generator factors and their effects on induction motors performance was studied. These effects include efficiency reduction which was shown for VDF=10%, 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. This derating leads to increase of energy consumption and cause more damages to consumers. With consideration to abundant consumption of this type of motors in Iran the amount of damages emerge from this phenomena was calculated and importance of preventing from non proper supply in induction motors was proved.

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