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TESTING OF DESIGNED DEVELOPED PROTOTYPE SIX PHASE INDUCTION MOTOR AND ANALYSIS OF PROBLEMS FACED IN ACTUAL DEVELOPMENT.

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ABSTRACT: *Amongst many types of electrical motors, induction motors still enjoy the same popularity as they did a century ago. Several factors which include robustness, low cost and low maintenance have made them popular for industrial applications when compared to dc and other ac motors. Another aspect in induction motor drives which has been researched recently is the use of multiphase induction motors where the number of stator phases is more than three.*

Multiphase induction motors have found many applications such as electric/hybrid vehicles, aerospace applications, ship propulsion etc. This paper focuses on testing of designed, developed prototype six phase induction motor at M/sJyoti Ltd,.Mogar, Anand, Gujarat and then comparison with equivalent three phase induction motor is discussed. Problems faced at the time of actual development are discussed in detail and solution to overcome those problems is given.

Keywords – *Six phase induction motor, winding design, and development.*

I. INTRODUCTION

Among the different multi-phase induction motor drives being researched, following important advantages are derived for the dual-3-phase induction motor having two stator winding sets spatially shifted by 30 electrical degrees with separated neutral.

The current stress of each semiconductor power device is reduced by one half compared with the same power 3-phase conventional induction motor.

The dual-3-phase solution can generate higher torque as compared to conventional three phase motor. This characteristic makes them convenient in high power and/or high current applications, such as ship propulsion, aerospace applications, and electric / hybrid vehicles (EV)

So when high power levels are required, the use of six-phase induction motor is one of the alternatives in industry. Six phase synchronous motor may also be used for high power applications, but weight of six phase induction motor is less as compared to six phase Synchronous motor of same rating.

I. ACTUAL DESIGN OF PROTOTYPE SIX PHASE INDUCTION MOTOR

As per the area of application, i.e. high power-high current, multiphase motors are of very high rating. So to design a techno economical motor, moderate and economical size which can very well show the characteristics of multiphase motor is chosen.

To begin with, an m-phase symmetrical induction machine, such that the spatial displacement between any two consecutive stator phases equals $\alpha = 2\pi/m$, is considered. Stator winding is treated as m–phase and it is assumed that the windings are sinusoidally distributed, so that all higher spatial harmonics of the magneto-motive force can be neglected. The phase number m can be either odd or even. When the number of phases is six, i.e. m = 6, there are two, three phase windings. The two, three phase windings are displaced by 600 in symmetrical design but there is a problem of magnetic circulating currents. So asymmetrical design is implemented in which two, three phase windings are displaced by 30^0, which eliminates (6n +1) order harmonics, where n = 1, 3, 5………..

A six phase machine can be easily constructed by splitting the 60^0 phase belt into two portions each spanning 30^0.The winding distribution factor increases from 0.965 for three phase to 1.0 for six phase for split phase belt connection.[1] A true six phase that retains the same winding pitch and distribution factor is shown in the table below. The last column represents six phase asymmetrical winding which is implemented for prototype motor.

The six-phase machine uses the same magnetic frame with the baseline machine. So initially the stator dimensions, stator size, rotor size etc. were kept same as 3 phase, 3 HP induction motor. And the same stator is rewound for making six phase.

Stator design depends upon number of stator slots. General expression for number of stator slots is given by,

$$S_s = m/2.p\ [2+K]\ \text{Slots} \qquad [1]$$

Where, S_s = No. of Stator Slots

m = No. of machine phases ; p = No. of machine poles ; K = 0,1,2…..

For Symmetrical ac winding: K = 0,2,4…..

For Asymmetrical ac winding: K = 1,3,5….

In this case no. of poles = 4, so putting the values of m, p, K in equation [1] we get,

$$S_s = (6/2).4[2+1] = 36 \qquad [2]$$

Thus it is a 4-pole machine with 36 stator slots. In order to keep the leakage distribution balanced, the phases are displaced among the two stator layers. The six-phases are constructed such that one three-phase group is displaced from the other one by 30 electrical degrees.

Thus it is an asymmetrical six phase machine

where;

$$\theta m = 2.\ \theta e / p \qquad [3]$$

$$\theta m = 2\ .30^{\circ} / 4 = 15^{\circ}\ \text{mechanical} \qquad [4]$$

$$\text{Slot pitch} = 360° / 36 = 10°\ \text{mechanical} \qquad [5]$$

Hence, the 30 electrical degrees displacement corresponds to $15^{\circ}/10^{\circ}$ = 1.5 slots.

It is not possible to implement such a configuration and an approximation has to be used. This is done as shown below:

One of the three-phase groups has the same structure of the baseline machine with half of the circuits and winding distributed in 3 slots per pole per phase (q_A = 3)

The second group is distributed into 4 slots per pole per phase (q_x = 4) but keeping the same number of conductors per pole per phase.

Initially the same dimensions as per 3 phase, 3 HP, induction motor have been used. And stator is divided into two parts and winding is carried out as discussed above.

Prototype six phase induction motor is developed in such a way that, first three phase set say, "ABC" has two pole pitches viz. 9 for outer layer and 7 for inner layer. While the second three phase set say "XYZ" has two pole pitches viz.8 for outer layer and 6 for inner layer. The number of poles is kept same for both the windings. Also wire gauge and number of turns are same for both the windings. The neutrals of two three phase sets are kept open. The motor is star connected.

II. PROBLEMS FACED IN DEVELOPMENT OF MOTOR

Motor developed with these parameters (used same dimensions as per three phase motor) have very compact winding.
Initially two three phase sets of developed motor are tested alternatively one by one from three phase supply and following points are noted:

Over heating is experienced even under no load condition.

Over heating has also lead to failure of insulation.

With these specifications, when one of the three phase sets was fed with three phase AC supply, the motor started vibrating.

Also because of high input voltage i.e. 415 V to one of the three phase sets say ABC, after sometime motor started burning.

Also there was a problem of Body earth because of complicated winding and proper insulation not done at the time of actual winding.

A. Solution to the Problem:

To overcome above said problems following steps are taken:

Over heating is caused due to I^2R losses. If the heat dissipating area can be increased and at the same time number of conductors and conductor size changed, it will affect the current. Thus the frame size of the motor is increased as per the calculations shown in next section. Also number of conductors is increased as per the slot. And conductor size is changed from 24 SWG to 22 SWG.

To avoid insulation failure due to overheating, the insulation class is changed from class B (1300) to class F (1550).

Vibration is experienced because of high torque. To overcome vibration, frame size is increased. This increases the mechanical strength of motor and eliminates third harmonic current injection.

The motor voltage is increased gradually up to 200 Volts, to overcome burning problem.
As frame size is increased slot area is increased thus there is no compact winding.

III. RE DEVELOPMENT WITH NEW SPECIFICATIONS: (Novel Design)

The practical problems faced at the time of actual development of prototype were overcome by using next higher standard stator stamping. As per the calculations for six phase motor the main dimensions are not same as three phases. But the stator slots, pole pitches are kept same.

The next higher standard dimension stamping available at the manufacturing unit near to the calculated value are selected. Standard Stator bore diameter available is 125 mm, nearest to the calculated value 124 mm. And stack length as per standard is selected as 100mm nearest to 102 mm.

Thus the motor is redesigned and developed with stator bore diameter increased from 105mm to 125mm. As per stator frame size, rotor slots changed from 33 to 28 as per standard. Instead of 96 conductors per slot of 24 SWG, 104 conductors per slot with 22 SWG conductors are used. And total number of turns is increased from 144 to 312. Insulation class is also changed from Class B (130^{o}C) to Class F (155^{o}C). These changes have reduced the stator resistance from 3.17 Ohms to 2.34 Ohms.

IV. TESTING

There is no standard separately for six phase induction motor. Thus the routine tests which are carried out for three phase motor, the same tests are carried out on prototype. It is considered like two, three phase induction motors sharing the same magnetic circuit and same shaft but electrically separated. Thus routine tests as per IS standards are carried out, by taking ABC and XYZ one by one.

HV Test :- A 2 KV voltage is given to the terminal box between phase to phase and phase to earth for one minute and there should be no sparking. If there is sparking, there may be inter turn fault.

Prototype six phase induction motor is tested like, two three phase stators sharing same shaft and same magnetic circuit and electrically separate. Prototype six phase induction motor satisfies this test, i.e. there is no sparking for both the three phase sets (ABC and XYZ).

A. **Insulation Resistance (IR) Test: -** Insulation resistance as per IS-325 should be 1 Mega Ohm.
   Prototype six phase induction motor has insulation resistance 1MΩ for both three phase sets.
B. **No load Test: -** Motor is run at rated voltage at no load and rated speed. No load test results with waveform are shown below.

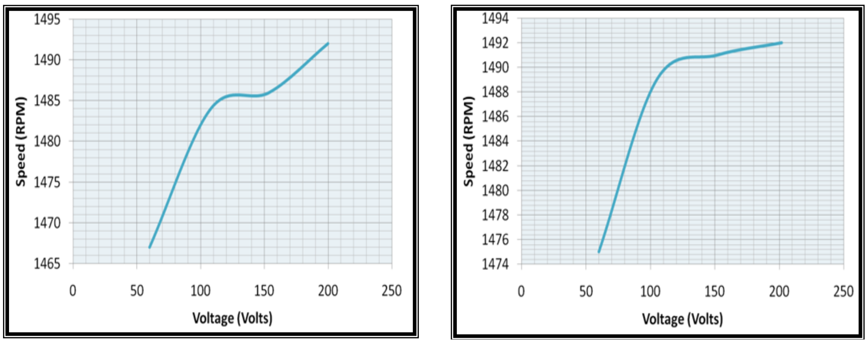

Fig.1 No Load Characteristic when ABC and XYZ energized separately, one by one.

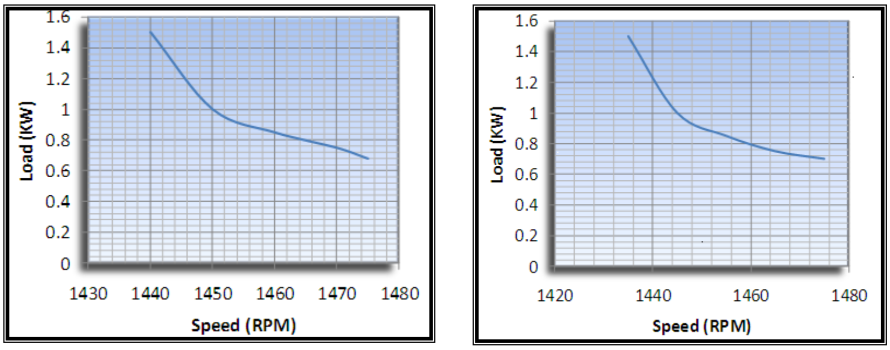

Fig.2 Load Test Characteristic when ABC and XYZ energized separately, one by one.

In no-load test, increasing voltage, increases the current and speed. While in load test, increasing current through load reduces speed.

V. CONCLUSION

The torque of six phase induction motor is much higher than equivalent three phase induction motor. Prototype six phase induction motor torque is 1.6 times that of equivalent three phase motor. In [2]-[8] torque improvement is obtained by third harmonic current injection. Third harmonic current injection needs large inductors. The application of multiphase induction motor is mainly in high power-high current applications so the use of inductor for current injection is uneconomical. Though the initial cost of six phase induction motor is increased as compared to three phase induction motor but at the same time efficiency and torque are significantly improved. Also torque improvement with third harmonic current injection is 1.4 times that of equivalent three phase induction motor [2]-[8] while the developed prototype six phase induction motor torque is 1.6 times that of equivalent three phase induction motor. As the motor rating increases it is tedious to arrange third harmonic current injection externally and also uneconomical.

From the no load and load tests conducted separately on ABC and XYZ, it is obvious that the prototype motor is highly reliable: If one of the three phase sets is not supplied the motor will continue to run as three phase and continuity of operation is maintained as the neutrals are separate.
Instead of copper conductors, aluminum conductors may be used to reduce the cost, thus making it more economical.

When both the three phase sets will be supplied simultaneously through inverters may get better results.

Actual Photograph at the time of Load test   Actual Photograph at the time of winding

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