O. A. Akinsanya / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 6, November- December 2012, pp.1097-1100

Transdesign Of A Three Phase Squirrel Cage Induction Motor

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ABSTRACT

Transdesign is the process of converting an idea that has already been used into another one by adding compensation or removing an information in order to modify it to suit a particular purpose. This paper presents the redesign concept as a radical method of revamping a dead electric motor back to usefulness. Data for this paper was got from direct measurement of parameter of a 2.5Hp discarded induction motor, while additional data were obtained from secondary sources. Combining the measured parameter with the assumed empirical constant, the wire guage was found to be 27 while the number of conduction/slot/phase was.66.With the a transdesigned electric motor with characteristic radically different from original design is achieved.

INTRODUCTION

Design, a creative translation of concept into reality, is the application of science, technology and invention to the realisation of a concept to achieve specific functions with optimum economy and efficiency (Say 1976). The purpose of engineering design is to develop a basic concept into a piece of equipment that can be reproduced in quantity and placed into use.

Designing is an adventure using observation and intelligence to explore new or modified possibilities. It is a part of human imagination, expressed in objects and activities and represents a powerful method of synthesizing many forms of knowledge and experiences.

Redesign or Transdesign is the process of converting an idea that has already been used into another one by adding compensation or removing an information in order to modify it to suit a particular purpose. Instances of redesigning abound in business and government. Road are redesigned and constructed to give motorist a smoother ride; individuals redo their home by sprucing up the decor e.t.c. Transdesigning is not a creative building up of possibilities rather it is a deductive analytical process to achieve a problem solving activity.

Electrical machines are electromechanical energy converters that either transforms energy from mechanical to electrical as in generators or converts energy from electrical to mechanical as in motors. The principle of electromechanical energy conversion is the cornerstone for machine analysis and it allows one to establish expressions of torque in terms of machines variables. All electrical machines have a magnetic system which produces the magnetic field and a set of windings producing the torque. The electric motor is a device which converts electrical energy into mechanical energy, simply the motor employs electrical power to generate magnetic field which forces the conductors of the armature to turn, and the rotating armature is used to drive a mechanical load (Pyrhönen et al,2008). Since the major part of all generated electrical power is sinusoidal in nature, most motors are designed for ac operation. DC motors encounter difficulties from the action of commutation, which involves brushes, brush holders, neutral planes, flashover etc. However, AC motors give trouble-free operation over long period of time, since the effect of slip ring is avoided. The squirrel cage induction motor is the one that is extensively used for various kinds of industrial drives because of its low cost, reliability, simplicity and ragged construction (Upadhyay, 2008). It also requires minimum maintenance, can start easily from rest, and has sufficiently high efficiency under normal running condition. However, its speed cannot be varied without sacrificing part of its efficiency.

Generally, squirrel cage induction motors get into final state of desrepair mainly due to failure of the armature winding. In many cases, the armature would have been rewound a number of times and sometimes in the process of rewinding identities are lost. The wire guage, number of turns of the coil, positioning or combination of the above could be wrong. Meanwhile, the entire rotor, the casing and connections are intact and the only ailing member is usually the stator winding. In the process which can be called transdesign or redesign concept, such motor can be reactivated from purely physical measurement of the stator parameters to achieve a successful operation from a discarded motor.

Therefore, the objective of the study is that, instead of throwing a dead motor or machine with lost parameters into the junk, transdesign process takes place to achieve possibilities with new characteristics.

2.0 METHODOLOGY

2.1 Data collection

Electric motor of lost parameters was collected in order to measure the stator parameters. These parameters are: number of slots and their size,

stator bore, D, active length L, air gap length, etc no of phases, (table 1).
Additional data were collected from secondary sources to obtain frequency, electric density magnetic loading, electric load, winding factor etc. (table 2)

2.2 Methods of measurement

The stator bore, D was measured with the aid of a vernier calliper while the active length L was measured with ruler, the difference between the stator bore and rotor diameter gave the air gap length, physical counting was done to obtain the number of slots.

2.3 Approach to data analysis

The following equations were used to achieve the redesign of the induction motor (Shanmugasundaram.et al, 1979):

$B = 2p\,\Phi_m/\pi DL.\ \ Wb/m^2$ .... eq. (1)

where B = specific magnetic loading
Φ = Flux per pole
P = Number of pairs of poles
L = axial length, m
D = rotor diameter, m

$Ac = 3 \times 2T_{ph}.I_{ph}/\pi D.$ Amp. Cond/m. .... (2)

where T_{ph} = numbers of turns/phase
I_{ph} = phase current
D = stator diameter
ac = specific electric loading

$\Phi = BL\gamma$ (3)

Where γ = pole pitch

$\gamma = \pi D/p$ (4)

D = Stator diameter, L = Stator length and p =no of pole pairs.

$Kd = \sin(m\,\alpha/2)/(m \sin \alpha/2)$ (5)

$S = 1.11K_w.\,\pi^2.B\,ac\,D^2Ln.$ (VA) (6)

Where S = VA rating
K_w = winding factor
n = speed of rotation

$N_s = 60f/p$ (7)

Where f = frequency

$n = Ns\,(1\text{-}s)$ (8)

$E_p = 4.44\,k_w f\,\Phi\,T_{ph}$ (9)

$Is = \text{kVA rating}/(3\,V_{ph})$ (10)

$J = I/A$ (11)

J = current density, A/mm^2
I = Conductor current, A
A = conductor area in mm^2

The VA rating is proportional to the average gap flux density B; the armature surface current density ac; the volume of the rotating member, D^2L product and the speed of rotation, n.
From studies, for normal 50Hz machines; B lies between 0.3 and 0.6 i.e $0.3 \le B \le 0.6$
The maximum flux density commonly employed is between 2.2T to 2.4T. The electric loading varies between 5000 and 45000 i.e $5000 \le ac \le 45000$, while the current density δ may lie between 3 and 8 A/mm^2

3.0 RESULTS AND DISCUSSION

A discarded motor can be reactivated by redesigning the stator winding from purely physical measurement of the stator core, the number of stator slots and size, the stator bore D, as well as the active length L and airgap length etc. A choice of few design constants such as specific magnetic and electric loadings speed of motor, frequency of power supply, winding factor, together with stator dimensions enable the input power to be calculated (table 1and 2).

The efficiency of an induction motor ranges from 0.8 to 0.92 p.u while the power factor ranges between 0.8 to 0.9 p.u; therefore for the redesign, 0.8 and 0.85 p.u were assumed for the efficiency and power factor respectively. Singh (1982) quoted the IEE regulation to have specified that the maximum value for the specific magnetic loading should not be more than $0.45Wb/m^2$ and for the redesign work the value used was $0.42\ Wb/m^2$.
Considering equation (3 & 4), the useful magnetic flux, $\Phi = 4.88 \times 10^{-3}$ Wb.
With number of slots/pole = 9, phase displacement $=20^o$, number of phases = 3, then
Distribution factor= 0.96 (equation 5) and for a unity pitch factor,
Winding factor = 0.96.
Since the motor is designed for star –delta starting and using equation (6),
the number of turns per phase N =399,
Total number of conductor in all slots = 3 x2 x 399 = 2394
Then conductor/slot = 66.5.
From equations (7) and (8), the motor speed n = 1425 rpm and equations (9) gives the
kVA rating, S = 2.74 kVA.
Similarly equation (10) gives the stator current /phase Is = 2.2 A

The shaft of the induction motor is short and stiff to maintain the necessary short airgap, the use of ball or roller bearing makes accurate centering of the rotor possible. Modern motors of small and medium rating are built to the standards of IEC72, which lists the coherent range of main structural dimension with centre heights between 56-1000mm. Apart from special machines, the manufacturer of small and medium- rated induction motor is concentrated into series of standard frames to cover a wide range of by adjustment of rotor diameter and length (Say, 1976). The frame houses a stator of given outside diameter D_o together with its bearing, end cover, etc and an active length L_o. The rating of a particular frame depends on its dimension. Specific magnetic and electric loadings, type of enclosure and the load characteristics. In designing of electric motors, excessive heat should be avoided and hence the current density in the copper conductor of continuously operated power device should be within 3-8 A/mm^2 (Fink and Beaty, 1978), therefore taking a current density of 5.4A/mm^2 and using equation (11) the required conductor area is A= 0.41mm^2 while the diameter, d= 0.72 mm of enamelled round wire and using the standard specification for copper wire, this corresponds to guage 27 of enamelled round copper conductor (Alexander, (2007).

This paper centres on redesigning of a three phase squirrel cage induction motor. It has two principal parts: the stator and the rotor. The laminated steel stator core is built up of silicon steel punching the assembled as a hollow cylinder in a fabricated cast stator frame. A distributed three phase stator winding is arranged in slots on the inner circumference. The rotor is cylindrical in form with the outer surface carrying the bars and short circuited with ring conductor at both ends. The three phase voltage is supplied to the stator and rotating magnetic field is developed there in and sweep over the rotor through the air gap. The rotor is induced with the magnetic field hence e.m.f is generated in it to produce its own magnetic field in the same direction with the stator speed.

With the parameters determined a rewinder can be brought in. However a single layer winding of constant span arrangement is recommended since it is appropriate for small and medium size induction motors. Single layer winding fall into two main classes:

i. Unbifurcated winding in which the coil comprising a pair of phase groups in adjacent pole-pitches are concentric.
ii. Bifurcated windings in which each group is split into two sets of concentric coils each sharing its return coil-sides with those of another group in the same phase.

The coils should be insulated from stator using slot liners which should fit into the slots exactly, leather voile type of insulation is suggested because of its high electric strength even at high temperature; good conductivity; non-deteriorating composition, easy workability and good mechanical properties.

Coils are better made on former and later transferred into slots taking cognisance of numbers of poles, number of slots and numbers of phases. The three phase motor should be round with as many coils as the number of slots. These coils are then grouped to produce three phase separate windings. The starting head of the coils will be brought out as motor terminals to allow for easy supply and starting arrangement.

The following test are recommended

i. Continuity test
ii. Insulation resistance test
iii. Running light test
iv. Locked rotor test
v. Speed measurement

When all the connection between poles of the winding have been completed and tested, the flexible leads to the supply attached and tied, the stator can then be sprayed with varnish and baked to secure the wire to provide further insulation. From the design parameters the rewinding operation is determined. Further calculations can be carried out to obtain other parameters like winding resistances, leakage reactance, magnetizing reactance, no load loss, equivalent resistance, no load power factor as well as short circuit power factor.

From these last values the performance characteristics of the motor can be practically predicted (table 4). It is equally necessary for safety considerations to estimate the expected temperature rise in the core and winding when the motor is operating on full load.

4.0 CONCLUSION

From the above discussions, it is obvious that transdesign or redesign is radically different from rewinding. For in the case of rewinding, the best that can be done is to faithfully reproduce the previous last record and where this record is wrong the rewinder can provide no help, whereas in this transdesign, the winding is being redesigned afresh. This redesign or transdesign concept is presented as a problem solving approach since virtually all electric motors in the country today are imported and even when enough machine designs have been done by the engineers in the country, transfer of such designs into products is yet to be manifested. The view is that a shift to redesign concept will be a realistic concern torwards sustainable development until such a time when design can be converted into physical product in Nigeria.

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Table 1 Measured Data

S/N	Parameter	Values
1	Airgap length	0.4mm
2	Number of stator slot	36
3	Active stator length	10cm
4	Stator Bore D	7.4cm

Table 2 Additional/**Assumed Data**

S/N	Parameter	Values
1	Specific magnetic loading, B	0.42Wb/m^2
2	Specific electric loading, ac	23000A/mm^2
3	Current Density, J	6A/mm^2
4	Frequency, f	50Hz
5	Winding factor, K_w	0.96
6	Maximum flux density Φ	2.2 – 2.4T
7	Power factor θ	0.85
8	No of pairs of pole, N	2
9	Efficiency	80%
10	Fractional slip	5%

Table 3: Calculated results

S/N	Quantity	Value
1	Winding factor K_w	0.96
2	Useful flux	0.00488 Wb
3	Number of turn	400 turns
4	Conduction/slot	66
5	Total number of conductor	2394
6	Phase current	2.2A
7	Conductor size	0.582m
8	Conductor guage	27
9	Specific electric loading	23000Amp/mm
10	Full load speed	1425 r.p.m

Table 4: Typical Results for running lamp test

S/N	Quantity	Values
1	Voltage	380 volts
2	Current	2.16 Amp
3	Speed	1420 r.p.m (No load)
4	Insulation resistance	Infinity
5	Resistance/phase	4.2 ohms