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Design of Energy Efficient Three Phase Squirrel Cage Induction Motor

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Abstract: - By using design of three phase squirrel cage induction motor we can improve the efficiency of the motor. As efficiency increases losses in motor decreases as well as power factor increases. As we know in industry 90% of total load is of induction motors, so it is very important to maintain power factor near unity. Therefore, by improving the efficiency of the three phase induction motor we can maintain power factor near unity. By comparing efficiency classes IE1, IE2 & IE3 we can say that how efficiency improves from IE1 to IE3. In this way energy gets efficient by improving design of three phase squirrel cage induction motors.

Key Words: - ***IE1, IE2, IE3, Power factor, efficiency.***

I. INTRODUCTION

For some years and associated with changes in the worldwide use of energy resources, new policies have been included concerning permissible levels of efficiency in SCIMs. Standard efficient motors named IE1 by the International Electro Technical Commission, are not existing in the market. Instead, high (IE2) and best (IE3) efficient motors are used. Therefore, the design criteria had to be revised to achieve these new levels of efficiency.

Squirrel cage induction motors are widely used in industry because of their robustness and low cost. It is observed that 80 to 90% of total electricity is consumed in industry by SCIM. Taking into account, 50% of electricity generated is used in industry. Hence it can be concluded that as SCIM are major electricity consumers. Therefore, reducing losses in these machines become a significant objective to be achieved.

Generally, induction motors are widely from several years in industries because of their many advantages like low cost, maintenance is less, full load power factor is good, etc. but it has disadvantage that is efficiency is less at light load condition. Hence there is large power loss taking place, hence it is need to design high efficient motor. That is possible with the use of magnetic wedges, of good quality material and change in design parameter of induction motor.

II. DESIGN OF A INDUCTION MOTOR

A. Procedure to design motor- Design of induction machine consist of:

- The main dimensions of the stator.
- Design of stator windings.
- Design of rotor and its windings.
- Performance characteristics.
- Design of main dimensions of stator

Main dimensions (D&L):

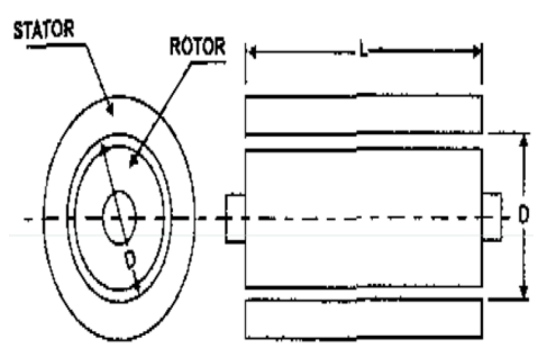

Fig.1. Main dimensions of a stator of a machine

Output equation of a machine is given by

$Q=C_oD^2L\ n_s$, where $C_o = (11B_{av}\ ac\ K_w \times 10^{-3})$

D2L = Q/C_o ns, where Q is given by

Q= (hp rating *0.746) (η*cosϕ)

Separation od D & L:

Ratio between gross length and pole pitch can be assumed as follows

- To obtain minimum overall cost: 1.5 to 2.0
- To obtain good efficiency: 1.4 to 1.6
- To obtain good overall design: 1.0 to 1.1
- To obtain good power factor: 1.0 to 1.3

The diameter of a machine should choose in a such a way that for normal design the peripheral velocity should be below 30 m/s and for specially designed rotor up to 60 m/s. If the core length exceeds 100mm to 125mm then the ventilation ducts are provided. The width of each duct is about 8-10 mm.

Turns per phase:

Flux/pole= B_{av} xлDL/P,

The emf equation is E_s= 4.44fϕT_s K_{ws}.......winding factor is assumed as 0.955

So, Ts= E_s/= 4.44fϕT_s K_{ws}

And, total no. of stator conductors = 2 Ts*3=6 Ts

Area of stator conductors:

Current density for stator windings is 3 to 5 amp/mm^2

Stator current /phase, I_s= Q/(3*E_{ph})

So a_s= $I_s/^{\delta}{}_{s,}$ where $^{\delta}{}_s$ is the current density in stator winding and a_s is area of each stator conductor.

Selection of number of stator slots:

Number of slots per pole per phase should not be less than 2 to avoid high leakage reactance. Most of the cases is taken 3. Slot pitch, for open slot 15 to 25 mm and slot pitch for semi closed slot- less than 15mm. according to this suitable numbers of slots are chosen.

Conductors/ stator slots:

Stator slot pitch at the air gap surface = τ_{ss}=лd/S_g, where S_g is the number of slots, so total no. of stator conductor = 6T_s

Then, conductor's/ stator slots= 6T_s/S_g

The number of stator conductor / slots must be an even number for double layer winding.

Area of stator slot:

Approximate area of each slot = (Cu area/ slot)/space factor Space factor is in between 0.25 to 0.4. width of each slot should be adjusted such that mean flux density in tooth lies between 1.3 to 1.7 Tesla. In general ratio of slot depth to slot width is d_{ss}/w_{ss} = 3 to 6.

Length of mean turn:

L_{mt} = 2L+2.3τ_p+0.24(up to 650 v)….obtained by empirical relationship.

Per phase resistance of stator winding:

resistance of stator winding per phase = (0.021 x L_{mt} x T_{ph})/as where L_{mt} is in meter and a_s is in mm^2. So total copper losses in stator winding =3(I_s)^{2}R

Stator teeth:

Flux density in stator teeth <1.7. so,Tesla mean tooth area / pole = (no. of slot / pole)*(net iron length)*(width of tooth). Where, width of tooth= ϕ/ 1.7*(slot/pole) *L.

Stator core:

Generally, the flux density in the stator core maybe assume varying between 1.2 to 1.4 Tesla. so, flux in the stator core section=1/2 ϕ

Area of stator core = ϕ/2B_c and area of stator core = Li x d_{cs}. Where d_{cs} = ϕ/ Li2B_{cs}. then outer diameter of the stator core can be calculated as ,

D_o= D+2dss+2d_{cs} where d_{ss} is the depth of the stator slot.

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III. Design Of Rotor

A. Rotor bar current:

By comparing MMF developed in rotor and stator bar current in rotor of squirrel cage induction motor can be determined.

Hence the bar current is given by,

$$Ib = (KwsxSsxZ's)xI'^{\gamma}/(kw^{\gamma}xSrxZ'^{\gamma});$$

Where,

Kws- winding factor of stator,

kw^{γ}- winding factor for the rotor,

Ss- number of stator slots,

Z's-number of conductors/stator slots,

Sr- number of rotor slots,

Z'^{γ}-number of conductor or rotor,

I'^{γ}- equivalent rotor current in terms of stator current and is given by

I'^{γ}= 0.85I where is stator current per phase.

B. Shape and size of the rotor slots:

Generally, semi closed slots and closed slots are to be designed for the squirrel cage induction motor. The rotor slots are employed with very small or narrow openings. The rotors with closed slots are given better performance to the motor in the following way.

- As the rotor is closed the motor draws lower magnetizing current.
- the air gap characteristics are better it gives reduced noise level.

C. Copper loss in rotor bars:

Copper losses in the rotor bars can be calculated by using the length and resistance of rotor bars.

Length of rotor bar l_b= L+ allowance for skewing rotor bar resistance = $0.021xl_b/I_b$

Copper loss in rotor bars =l_b^2x rb x number of rotor bars.

D. End ring current:

By connecting rotor bars to the end rings at both the end rings all the rotor bars are short circuited. Due to rotating magnetic field an emf will be induced in the rotor bars, which will be sinusoidal over one pole pitch. Due to this induced emf and as we know the rotor is a short circuited, there will be current flow through it.

IV. Simulation using ANSYS Maxwell and Result

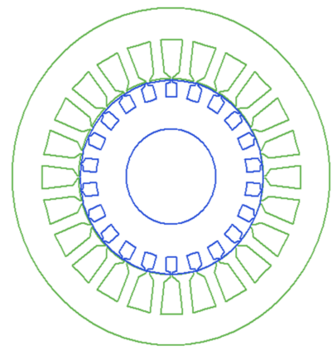

Fig.2. Simulation using ANSYS Maxwell

Design Sheet Specifications: -

KW=2.2, Voltage=400V, Phase=3connection= Delta, Frequency=50Hz, Type=Cage

	Parameters	Nomenclature	Rating
Rating	Full load output		2.2kW
	Line Voltage		400V
	Frequency	F	50Hz
	Phases		3
	Efficiency		0.8
	Power factor		0.825
	No. of poles	P	4
	Synchronous r.p.m.	n_s	25
	kVA input		3.33
	Full load line current		4.8A
Loading	Specific magnetic loading	Bav	0.44 Wb/m^2
	Specific electric loading	Ac	21000 A/m
	Output coefficient	C_0	97

	D^2L		$1.375*10^{-3}$ m^3
Stator	Types of laminations		0.5mm thick
	Types of winding		Single layer mush
	Connection		Delta
	Phase voltage	E_s	400V
	Flux per pole		$4.54*10^{-3}$Wb
	Turns per pole	T_s	416
	Number of slots	S_s	24
	Slots per pole		6
	Slot per pole per phase	q_s	2
	Coil span	C_s	5 slots
	Distribution factor	K_d	0.966
	Pitch factor	K_p	0.9659
	Winding factor	K_{ws}	0.934
	Slot pitch	y_{ss}	13.75mm
	Conductor per slot	Z_{ss}	104
	Conductor bare: Insulated diameter area		0.95mm
			1.041mm
			$0.709mm^2$
	Current density		$3.91A/mm^2$
	Length of mean turn	L_{mts}	0.68mm
	Phase resistance at 75^0 C	r_s	8.37 ohm
	Copper loss at full load	$3Is^2r_s$	193W

	Depth of stator core	d_{cs}	17mm
	Outer diameter of stator laminations	D_c	181mm
Rotor	Length of air gap	l_a	0.3mm
	Diameter of rotor	D_a	104mm
	Types of winding		Squirrel cage
	Number of slots	S_r	22
	Conductors per slot	Z_{sr}	1
	Winding factor	K_{wr}	1
	Slot pitch	y_{sr}	14.9 mm
	Rotor bar current	I_b	244A
	Rotor bar cross section area	a_b	$44.6\ mm^2$
	Copper loss in rotor bars	$S_rI_b^2r_b$	101W
	Resistance of rotor bar	r_b	$77.7*10^{-6}$ohm
	End ring current	I_e	428A
	Copper loss in end ring	$2\ I_e^2\ R_e$	23W
	Depth of rotor core	d_{cr}	17mm

Rated Output	Frame Size	Full Load Speed	Full Load Current	Breakaway Torque in terms of full load torque	Locked RotorCurrent in terms of full load current (equal or below) IE2	IE3	IE4	Nominal efficiency (%) IE2	IE3	IE4
kW (1)	(2)	rev/min (3)	Max A (4)	Percent (5)	Percent (6)	Percent (7)	Percent (8)	Percent (9)	Percent (10)	Percent (11)
0.12	71	620	0.8	150	500	550	600	39.5	50.7	62.3
0.18	80	630	1.0	150	520	550	600	45.9	58.7	67.2
0.25	80	630	1.2	150	520	550	600	50.6	64.1	70.8
0.37	90S	640	1.5	150	550	600	650	56.1	69.3	74.3
0.55	90L	640	2.1	150	550	650	650	61.7	73.0	77.0
0.75	100L	650	2.7	150	550	650	650	66.2	75.0	78.4
1.1	100L	660	3.5	150	550	650	650	70.8	77.7	80.8
1.5	112M	670	4.5	150	550	650	650	74.1	79.7	82.6
2.2	132S	680	6.1	140	600	700	780	77.6	81.9	84.5
3.7	160M	690	9.8	140	600	700	780	81.4	84.5	86.8
5.5	160M	690	14.2	140	600	700	780	83.8	86.2	88.3
7.5	160L	695	19.0	140	600	700	780	85.3	87.3	89.3
11.0	180L	700	26.0	140	600	700	780	86.9	88.6	90.4
15.0	200L	705	35.0	130	600	700	780	88.0	89.6	91.2
18.5	225S	705	45.0	130	600	700	780	88.6	90.1	91.7
22.0	225M	710	52.0	130	600	700	780	89.1	90.6	92.1
30.0	250M	710	70.0	130	600	700	780	89.8	91.3	92.7
37.0	280S	710	86.0	130	600	700	780	90.3	91.8	93.1
45.0	280M	720	99.0	130	600	700	780	90.7	92.2	93.4
55.0	315S	720	118.0	130	600	700	780	91.0	92.5	93.7
75.0	315M	730	153.0	130	600	700	780	91.6	93.1	94.2
90.0	315M	730	182.0	130	600	700	780	91.9	93.4	94.4

Values of performance characteristics of 8 pole line operated ac motors

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V. CONCLUSION

In this paper stator design as well as rotor design of induction motor is done and using the design parameters simulation design are analyzed. Addition of magnetic wedges in the stator slots reduces the air gap reluctance and the zigzag magnetic flux, which increases stray losses. This improves efficiency because by reducing the air gap reluctance, the stator currents are reducing and the copper losses also reduce. So the stator is designed with addition of the magnetic wedges and the analysis part is going on.

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