Design Optimization of 3 Phase Induction Motor

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Abstract

The induction motor due to its overall good characteristics forms the most prevalent selection of industrial applications worldwide. To encounter the raising call of energy disaster, attempts have been made by either trapping energy from inexhaustible sources or by enhancing the operating efficiency of devices requiring bulk consumption of electric energy. Any remarkable augmentation in the operating efficiency of induction motor will, therefore, assist our endeavor at energy preservation. There is an essential selection into utilizing either a lower cost die cast or fabricated aluminum rotor versus the most extravagant copper bar rotor, while constructing a squirrel-cage induction motor. However, there are crucial benefits in electrical energy efficiency by using a copper in the rotor of motors. This paper depicts an optimal design tactic to optimize three-phase induction motor in assembling process. The optimally represented motor is equated with an existing motor having the same ratings.

Keywords: Efficiency, Optimization, Energy Saving, Pole Arc & Pole Pitch, Induction Motor etc

Nomenclature

B_{av}	Average Air-gap Flux Density (Wb/m^2)
ac	Ampere Conductor(ac/m)
P	Number of Pole
η	Efficiency
Ks	Stacking Factor
Kw	Winding Factor
m	Slot / pole / phase
Greek symbols	
α	Pole arc to Pole Pitch Ratio
Subscripts	
HP	Horse Power
KVA	Kilo Volt-Ampere

1. Introduction

There is a huge gap between demand and supply of electric power in India; this is leading us to focus on to use energy efficient conservation. Numerous attempts have been made to most efficiency from renewable energy souse and to increase efficiency of generation, transmission and utilization devices. Due to its simple and rousted construction three phase induction motor (IM) is the heart if the any industry [1][2]. Induction motors are considered to be the main workhorse and are used in very large number in a variety of applications which include sectors like office, home, farm and industry [3][4][5]. Any significant improvement in the operating efficiency of induction motor will, therefore, help our effort at energy conservation. This can be achieved by taking recourse to design optimization techniques [11].

In recent years digital computers are being widely used in all stages of electrical machine design namely analysis, synthesis and optimization. In the optimization phase of the problem the task is to get a design having minimum material cost, minimum weight or an optimum performance feature like maximum efficiency [3][4][10]. Until recently, the optimum design was chosen after comparing a number of feasible designs. The computer was used to make a detailed analysis of design and for obtaining a fairly large number of, alternate designs [4][12].

For this paper, to study design optimisation problem this paper is divided in two sections. In first half procedure will deal with the mathematical aspects, assumption and include the formulation, to create an algorithm to solve the design optimization problem [13]. And calculate main design parameter for few IM. In second half it will study the effect of change in variation of some key assumption like B_{av} and ac to its minimum and maximum theoretical values on the main design parameters on the IM.

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2. Flowchart for Design Optimization

The flow chart for design of three phase induction motor which is shown in Fig 1(a) and the flow chart for calculation of main dimension for IM is shown in Fig. 1(b) [1][2].

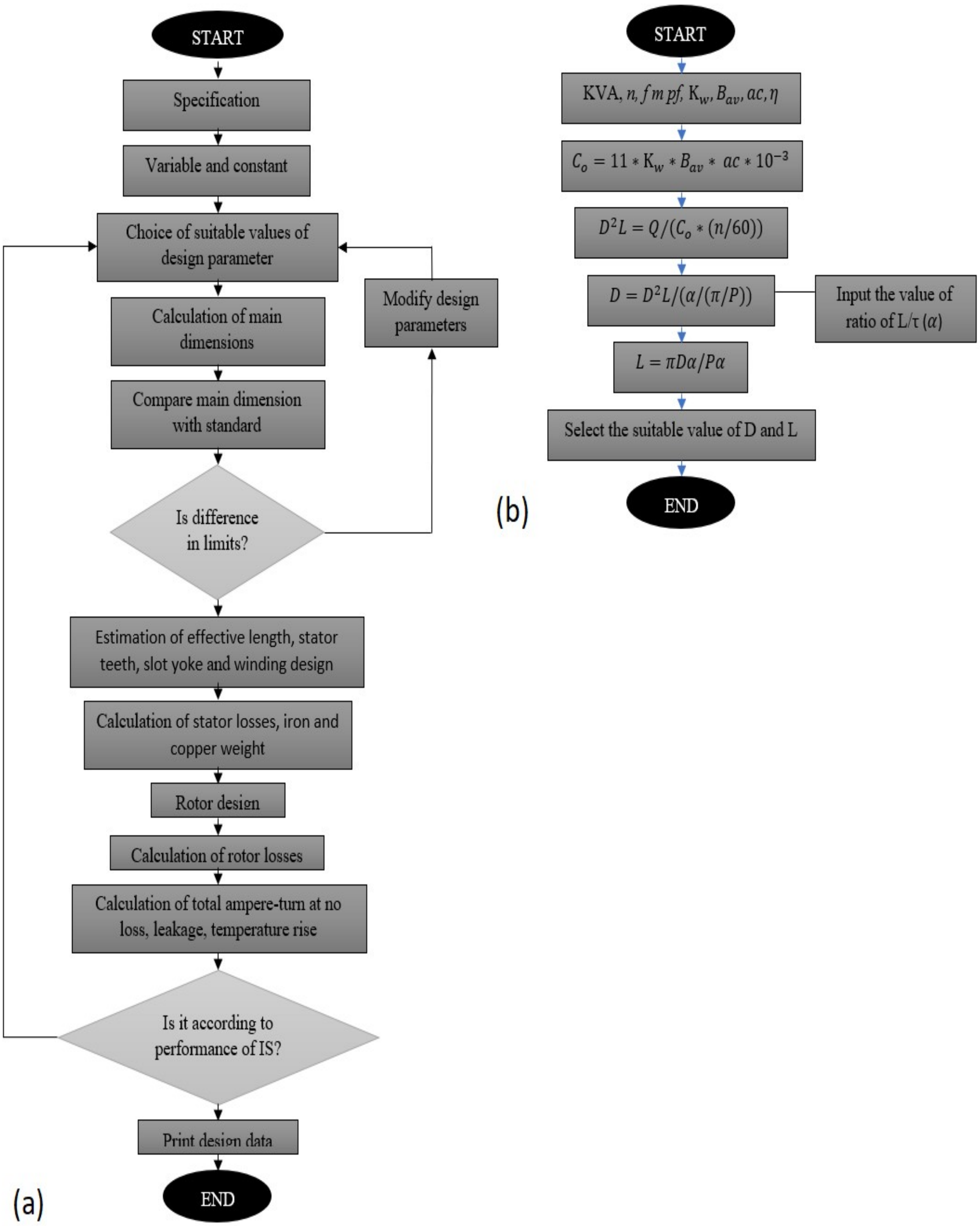

Fig. 1. Flowchart for (a) Overall design of three- phase IM (b) Main Diminution of IM [1]

3. Design of Induction Motor

The flow chart for design of three phase induction motor which is shown in Fig 1(a) and the flow chart for calculation of main dimension for IM is shown in Fig. 1(b) [1][2][12].

3.1 Design Optimization Problem

The design optimization problem of induction motor is formulated as a general nonlinear programming problem, as a follow:
Such that F(X) is optimum where X ($x_1, x_2, x_3, x_4, x_5, x_6, \ldots\ldots\ldots, x_n$) is the set of independent variables, which is representation of the electric and magnetic circuit of the machine. These parameters have considerable effect on the cost and performance of the motor. For this paper there are certain considering of few quantities for optimization problem which are given below:

1. Stator bore diameter (m) (x1)
2. Stator stack length (m) (x2)
3. Total number of stator conductor (x3)
4. Flux density in stator teeth (wb/m²) (x4)
5. Current in stator conductor (A) (x5)
6. End ring current (A) (x6)
7. Rotor bar current (A) (x7)

Other design parameter of machine can either find from above quantities or treated as fixed for any particular design based on application. The objective function to be maximized is F(X). The following constraints are imposed on the design optimization problem.

1. Max. stator/rotor tooth flux density ≤ 2.0
2. Full load slip ≤0.055
3. per unit maximum torque ≤ 1.0
4. Full load power factor ≥ 0.8
5. per unit starting torque ≤ 1.0
6. Full load efficiency≥ 0.75
7. per unit starting current ≤ 6.5
8. Per unit no load current ≤ 0.5

3.2 Optimization using Algorithm

In this paper, to attend optimum results of squirrel cage induction motor, one has to considered three different power rating of induction motors as per IS, which are mentioned as below:

- 1HP Induction motor (η-0.77, pf-0.78)
- 3HP Induction motor (η-0.83, pf-0.78)
- 5HP Induction motor (η-0.85, pf-0.78)

The rating of this motor is taken from the IS 1599 and the main parameters, efficiency and power factor is also taken from this IS 1599 for 4 Pole IE 2 motors [5] [7][10]. In this process, to design the IM some initial assumption has to be made like B_{av}, ac, α and many more which are mentioned below:

V = 415 V	ac = 23,000 ac/m
P = 4	$\alpha = 1.75$
M = 3	$K_w = 0.955$
$B_{av} = 0.45$ wb/m^2	$K_s = 0.9$

By considering above assumption, the calculated basic design parameters for above motors as mentioned below here,

Table 1. Design Parameters for IM

	1 HP	**3 HP**	**5 HP**
X1 (m)	0.0693	0.0974	0.1146
X2 (m)	0.0952	0.1339	0.1275
X3	2909	1470	1063
X4 (wb/m²)	0.70	0.99	1.16
X5 (A)	1.73	4.81	7.83
X6 (A)	295.2	415.3	188.5
X7 (A)	132.4	186.3	219.2

4. Observation and Analysis

The value of B_{av} and ac is for any IM is varying according to the required performance, this also effect the manufacturing and running cost of the IM. Here the effect of B_{av} and ac on different parameter on different motor is shown.

4.1. Effect of Air-Gap Flux Density

- For 1 HP Motor:

Airgap Flux Density (wb/m^2)	Stator Bore Diameter (m)	Stator Stack length (m)	Current in Stator Conductor (Is) (A)	Stator Conductor Per Slot	Stator Turns Per Phase	Flux Density in Stator Teeth (wb/m^2)	End Ring Current (A)	Cu Losses in End Ring (W)
0.3	0.079	0.109	1.73	93	185.66	0.54	337.42	8.83
0.42	0.071	0.097	1.73	83	166	0.67	301.62	5.8
0.5	0.067	0.092	1.73	78	156.66	0.75	284.59	4.63
0.58	0.064	0.087	1.73	75	149	0.83	270.85	3.8
0.62	0.062	0.086	1.73	73	145.66	0.87	264.9	3.48

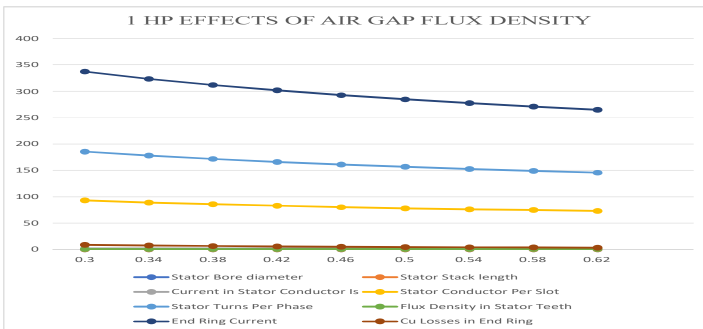

Fig 2. Effects of Air gap flux density on 1HP IM

- For 3 HP Motor:

Airgap Flux Density (wb/m^2)	Stator Bore Diameter (m)	Stator Stack length (m)	Current in Stator Conductor (Is) (A)	Stator Conductor Per Slot	Stator Turns Per Phase	Flux Density in Stator Teeth (wb/m^2)	End Ring Current (A)	Cu Losses in End Ring (W)
0.3	0.112	0.153	4.81	47	93.66	0.75	475.06	29.3
0.42	0.1	0.137	4.81	42	83.66	0.94	424.66	20.08
0.5	0.094	0.129	4.81	39	79	1.06	400.68	16.39
0.58	0.09	0.123	4.81	38	75.33	1.17	381.34	13.75
0.62	0.088	0.12	4.81	37	73.66	1.22	372.96	12.7

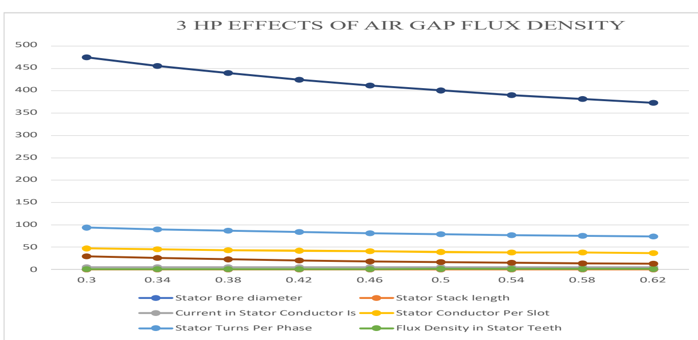

Fig. 3. Effects of Air gap flux density on 3HP IM

- For 5 HP Motor:

Airgap Flux Density (wb/m^2)	Stator Bore Diameter (m)	Stator Stack length (m)	Current in Stator Conductor (Is) (A)	Stator Conductor Per Slot	Stator Turns Per Phase	Flux Density in Stator Teeth (wb/m^2)	End Ring Current (A)	Cu Losses in End Ring (W)
0.3	0.13	0.179	7.65	34	68	0.89	558.15	50.77
0.42	0.116	0.16	7.65	30	60.66	1.11	498.93	34.87
0.5	0.11	0.151	7.65	29	57.33	1.25	470.76	28.62
0.58	0.105	0.144	7.65	27	54.33	1.38	448.04	24.16
0.62	0.102	0.14	7.65	27	53.33	1.44	438.19	22.38

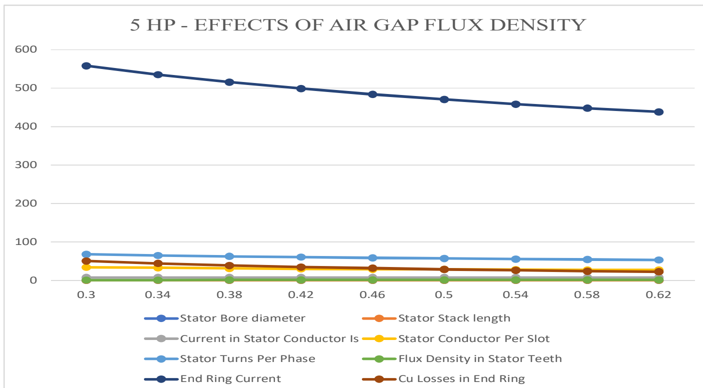

Fig. 4. Effects of Air gap flux density on 5HP IM

4.2 Effects of Ampere Conductor

- For 1 HP Motor:

Ampere Conductor (ac/m)	Stator Bore Diameter (m)	Stator Stack length (m)	Current in Stator Conductor (Is) (A)	Stator Conductor Per Slot	Stator Turns Per Phase	Flux Density in Stator Teeth (wb/m^2)	End Ring Current (A)	Cu Losses in End Ring (W)
5000	0.115	0.158	1.73	29	176	47.8	106.57	1.55
15000	0.08	0.11	1.73	61	366	99.44	221.67	3.86
25000	0.067	0.093	1.73	86	514	139.78	311.61	5.63
35000	0.06	0.083	1.73	107	644	174.93	389.97	7.03
45000	0.055	0.076	1.73	127	761	206.84	461.1	8.13

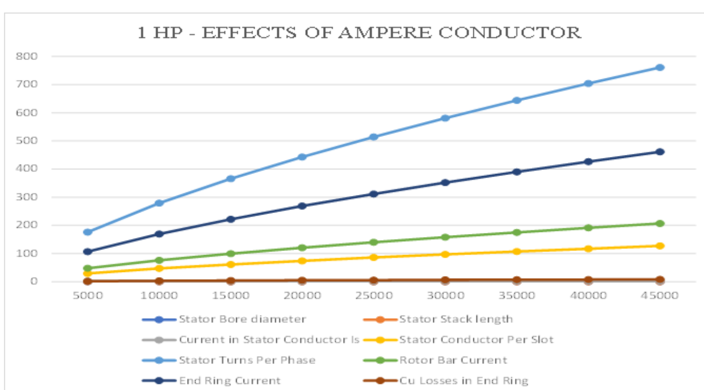

Fig 5. Effects of Ampere Conductor on 1HP IM

- For 3 HP Motor:

Ampere Conductor (ac/m)	Stator Bore Diameter (m)	Stator Stack length (m)	Current in Stator Conductor (Is) (A)	Stator Conductor Per Slot	Stator Turns Per Phase	Flux Density in Stator Teeth (wb/m^2)	End Ring Current (A)	Cu Losses in End Ring (W)
5000	0.162	0.223	4.81	15	89	67.3	150.04	4.82
15000	0.112	0.154	4.81	31	185	140	312.1	12.87
25000	0.095	0.13	4.81	43	259	196.8	438.72	19.86
35000	0.085	0.116	4.81	54	325	246.29	549.05	26.12
45000	0.078	0.107	4.81	64	384	291.21	649.19	31.79

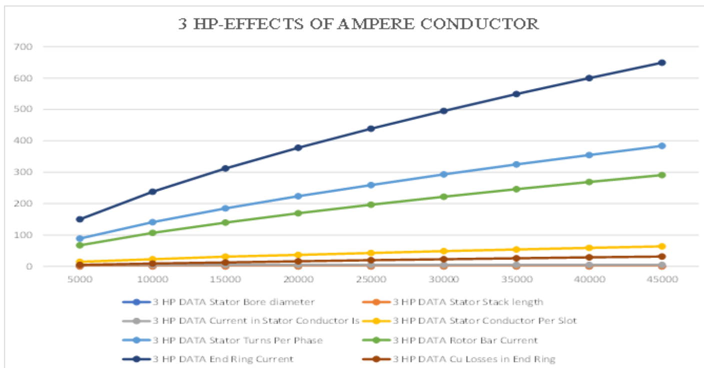

Fig 6. Effects of Ampere Conductor on 3HP IM

- For 5 HP Motor:

Ampere Conductor (ac/m)	Stator Bore Diameter (m)	Stator Stack length (m)	Current in Stator Conductor (Is) (A)	Stator Conductor Per Slot	Stator Turns Per Phase	Flux Density in Stator Teeth (wb/m^2)	End Ring Current (A)	Cu Losses in End Ring (W)
5000	0.189	0.26	7.65	11	64	79.08	176.28	8.1
15000	0.131	0.18	7.65	22	134	164.48	366.69	22.13
25000	0.111	0.152	7.65	31	188	231.22	515.46	34.67
35000	0.099	0.136	7.65	39	235	289.36	645.08	46.21
45000	0.091	0.125	7.65	46	278	342.14	762.74	56.94

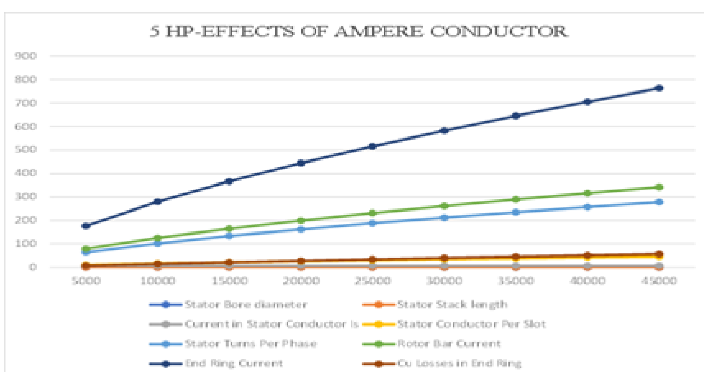

Fig. 7. Effects of Ampere Conductor on 5HP IM

These graphs depict that the effect of the B_{av} and ac has significant impact on the various factors like on bore of diameter, stack length of stator, number of conductor in stator, current in stator conductor and rotor bar, which has significant effect on cost and performance of motor.

5. Conclusion

With the help of such program, one can create a design sheet of any rating of induction motor. This has been done successfully achieved for 3 phase, 415 V, 50 Hz, 4 pole machines of 1 HP, 3 HP and 5 HP. In the process, It is also observe that the effect of varying the air gap flux density on different parts and rating of the motor for different power capacity. Similarly, effect can be observed by changing the ampere conductor in program. By investigating the behavior of the IM in this parameter, it will be easy for the manufacture to design induction motor which is better in terms of manufacturing cost and running cost. However, it is clear that this will indeed, make the optimized design more acceptable to the manufacturers and consumers.

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