CAD and FE analysis of Three Phase Induction Motor

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***Abstract*——In this paper, a comprehensive computer-aided design (CAD) procedure for three phase induction motor is presented. The basic output equations are derived and used for the design algorithm. The developed CAD program gives the design data and the calculated performances of the motor. The design variables such as air gap flux density, slot electric loading, winding factor, stator current density, slot space factor, flux density in the stator back iron, etc., are assumed. Three different motors rating are designed using the developed program, and then finite-element analyses are carried out to validate the designs.**

Keywords—induction motor, computer-aided design (CAD) of motor, finite-element (FE) analysis.

I. INTRODUCTION

Electrical motors are extensively used in commercial and industrial applications. Electrical motors are an important part of any electrical system because they consume about 65% to 70% of all electricity generated. Among all the motors, induction motors are the most widely used electric motors in industry. It offers reasonable performance, low maintenance, robust construction, a manageable torque-speed curve, stable operation under load and satisfactory efficiency. Development of a computer-aided design (CAD) program for the design and performance evaluation of three-phase induction motors is attempted, and the details of the steps involved along with a flowchart and recommendations are given in this paper. The design data of the motor obtained from this program, if needed, can be used as the input for further optimization of the designs using finite-element (FE) techniques. The design algorithm includes a complete design procedure, data libraries like standard wire gauge, magnetic material properties, etc. and an interactive input and output facility. Three different motors are designed using the developed program. The results are analyzed using a FE method, and the validity of the developed CAD programis established.

II. CONCEPTUAL DESIGN

The main purpose of designing an induction motor is to obtain the complete physical dimensions of all the parts of the machine to satisfy the customer specifications. The following design details are required.

A .Main Dimensions
B.Stator Design
C.Rotor Design
D.Performance Calculation.

Output Equation

kVA rating of machine of a 3- phase induction motor is

$$Q = 3E_{Ph} \times I_{Ph} \times 10^{-3} \quad kVA \tag{1}$$

Where,
E_{ph}=Induced emf per phase.
I_{ph}=Current per phase.
The output equation of 3-phase induction motor is,

$$Q = C_0 D^2 L n_s \quad kVA \tag{2}$$

$$Where, C_0 = Output\ Co-efficient = 11 \times 10^{-3}\, \bar{B}_{av}\, \bar{ac}\, Cos\varphi\eta$$

B_{av}=Specific magnetic loading.
ac=Specific electric loading.
L=stack length.
D=Stator bore Diameter.
n_s=synchronous speed inr.p.s.

Estimation of main dimensions (D, L)

So, from equation (2)

$$D^2 L = \frac{Q}{C_0 n_s} \tag{3}$$

D and L are calculated based on assumption of length to pole pitch ratio. Dimensions of magnetic circuits are calculated based on flux and permissible flux density of magnetic materials.

III. COMPUTER AIDED DESIGN (CAD)

The flowchart of the developed CAD program for the three phase induction motor is given in fig. 1. Motor specifications, type of configuration, material types, and other assumed data for the design are the input. The outer loop is to set and correct the assumed efficiency. The CAD program designs the motor and calculates the actual efficiency. The correction loop is active till the error between the assumed efficiency and the actual efficiency is within the given limit. As given in the flowchart of the developed CAD program in Fig. 2, the calculation of the main dimensions, stator design, rotor design, and the performance calculations are the main four stages of the design. The airgap flux density, slot electric loading, winding factor, stacking factor, stator current density, slot space factor, flux density in the stator back iron, etc., are assumed as fixed input parameters in the design. The phase current is decided by the power requirement, and induced emf decides the number conductors per slot.

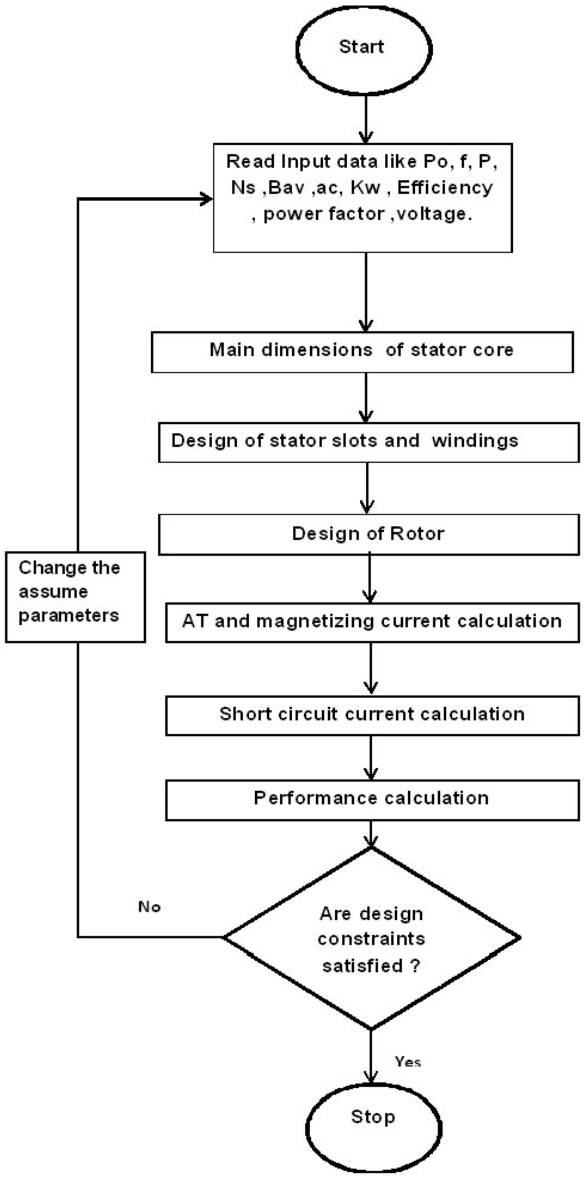

Fig.1. Flowchart for CAD of three phase induction motor

Three motors with the following ratings were designed using the developed CAD program: 2.2 kW,415 V,50 Hz,4-pole; 3.73 kW,415 V,50 Hz,4-pole; 37 kW,415 V,50 Hz,4-pole.

Table 1

DESIGN OUTPUTS OF THE THREE PHASE INDUCTION MOTORS OBTAINED USING THE DEVELOPED CAD PROGRAM

Performance	**2.2 kW**	**3.73 kW**	**37 kW**
Full load efficiency(%)	81.83	85.96	92.9
Stator outer diameter(mm)	206.1	239.5	440.7
Stator inner diameter(mm)	105	124.8	268.2
Stack length(mm)	125	147.1	316
Length of air gap(mm)	0.43	0.471	0.782
Total loss(kW)	0.488	0.609	2.78
Output power(kW)	2.2	3.73	37
Input power(kW)	2.688	4.34	39.78

IV.VALIDATION OF THE CAD RESULTS BY FE ANALYSIS

The accuracy of the developed CAD program is established by conducting 3-D FE analyses of the designed motors . FE analysis is carried out by MotorSolve IM. MotorSolve IM is a comprehensive tool within which modelling ,design iteration and design validation can be carried out for induction machines. To facilitate this, user friendly and powerful modelling features as well as multiple types of analysis options of varying degrees of approximation and complexity have been implemented. These include equivalent circuit based analysis, AC analysis, PWM and dynamical motionsimulations. FE results is given in Table II

Table 2

DESIGN OUTPUTS OF THE THREE PHASE INDUCTION MOTORS OBTAINED USING THE FE ANALYSIS

Performance	**2.2 kW**	**3.73 kW**	**37 kW**
Full load efficiency(%)	81.80	85.8	92.7
Torque(Nm)	14.9	24.9	243
Power factor	0.814	0.83	0.86
Total loss(kW)	0.490	0.620	2.91
Output power(kW)	2.2	3.73	37
Input power(kW)	2.68	4.37	39.8

A comparison of CAD and FE results is given in Table 3. It is observed that the results are within the acceptance tolerance; however, the minor difference between the two can be attributed to the empirical design coefficients and formulae used in the CAD program.

Table 3

A comparison of CAD and FE results of 2.2 kW,415 V,50 Hz,4-pole three phase induction motor

Performance	**CAD**	**FE SOFTWARE**
Full load efficiency(%)	81.83	81.80
Power factor	0.80	0.814
Total loss(kW)	0.488	0.490
Output power(kW)	2.2	2.2
Input power(kW)	2.688	2.68
Flux density in stator core(Wb/m^2)	1.185	1.12
Flux density in stator teeth(Wb/m^2)	1.50	1.57
Flux density in rotor teeth(Wb/m^2)	1.36	1.37
Flux density in air gap(Wb/m^2)	0.45	0.44

The flux density plot of 2.2 kW,415 V,50 Hz,4-pole three phase induction motor is shown in fig. 2.

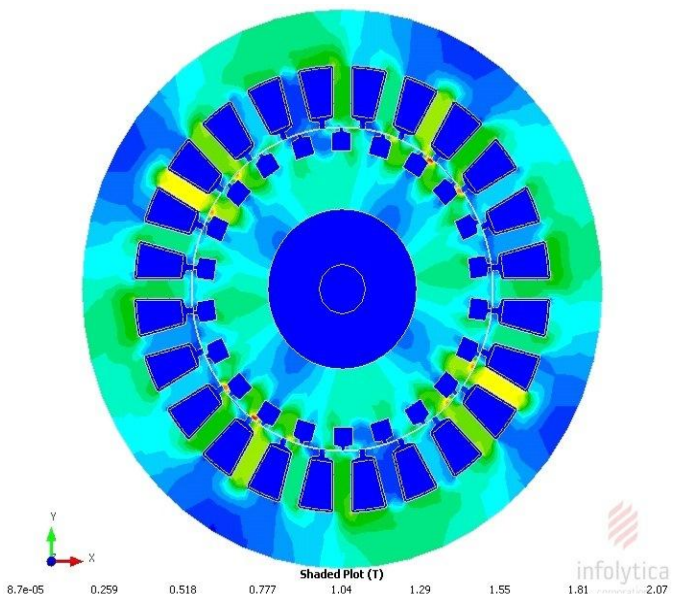

Figure 2

The torque-speed characteristics of the designed motor, obtained using FE analysis is given in fig. 3

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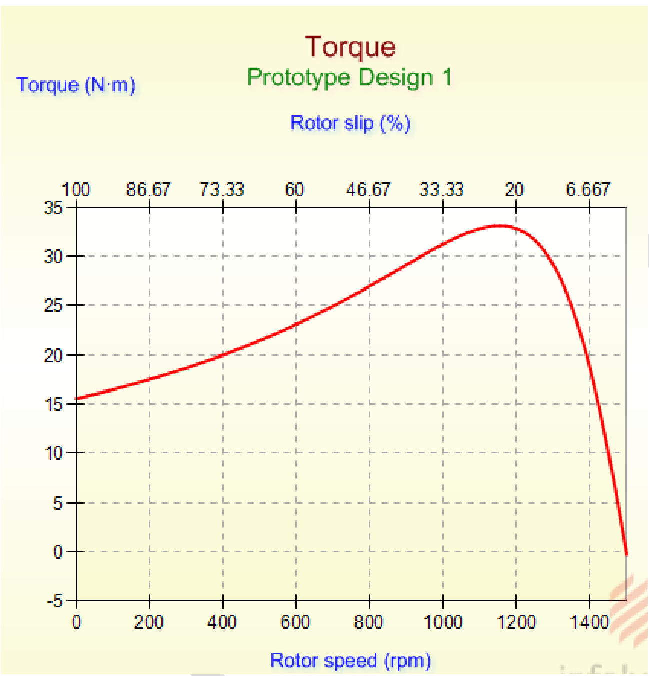

Figure 3

The efficiency curve obtained using FE analysis is shown in fig.4.

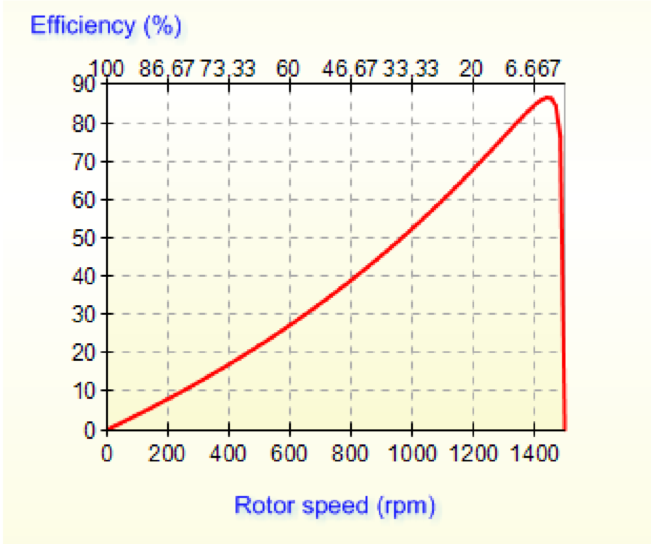

Figure 4

V. CONCLUSION

A comprehensive CAD procedure involving the derivation of the output equation and one self-corrective loops for the efficiency for the three phase induction motor is presented. The result of three different rating motors arrived using developed CAD program. The CAD-based designs are validated using the FE analyses. The results of FE analysis and CAD are fairly matching.

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