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Design Improvement of the Premium Efficiency Induction Motor for Higher Efficiency & Cost Reduction

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Abstract

Motor market is moving to premium efficiency and motor manufacturers around the globe are taking strategic efforts to increase the efficiency without increasing materials and manufacturing cost. The stator winding type plays an important role in deciding the efficiency, performance & the cost of induction motor. In this paper, the solution for motor efficiency improvement and cost reduction by implementing single layer winding is discussed. An attempt is made to improve the efficiency, minimize the cost and production time of premium efficiency motor by optimizing its winding design from double layer to single layer. A prototype manufactured, validates the feasibility of the designed winding and the built model, which is suitable for efficient operation at various loading conditions. An experimental comparison of a double and single layer winding premium efficiency motor, with regard to input power, losses, efficiency, cost and production time considering the same fundamental rated operating conditions, is presented. The test results obtained from prototype ensures the considerable increase in the efficiency, reduction in losses, cost and production time. This design solution is achieved without changing the frame size and stator geometry. However, it should be noted that the single layer winding design is feasible only if it is properly designed taking into account harmonics content and layer thickness.

Keywords: Premium Efficiency Motor; Single Layer Winding; Losses; Efficiency; Cost Reduction; IEC 60034-2-1; IEC 60034-30-1standard.

NOMENCLATURE

I = average line current, A

f = supply frequency, Hz

n = operating speed, s^{-1}

cos ϕ = power factor

p = number of poles

P = power, kW

P_1 = input power, kW

P_2 = output power, kW

P_{fe} = iron/core losses, kW

Pc= constant loss, kW

P_{fw}=friction and windage losses, kW

Ps = stator copper loss, kW

P_{LL} = additional-load losses, kW

P_T = total losses, kW

s = slip

R = winding resistance, Ω

T = torque, Nm

U= terminal voltage, V

U_N = rated voltage, V

η = efficiency, %

K_w = winding factor

θw = winding temperature, °C

INTRODUCTION

Induction motors are industry's basic need and are prime source of energy consumption worldwide. So, efficiency of induction motors need to be increased. Hence, motor manufacturers face an additional burden of achieving high efficiency for regulatory and business reasons. [2] Premium efficiency induction motors are more reliable, consume less energy and produce less waste heat.

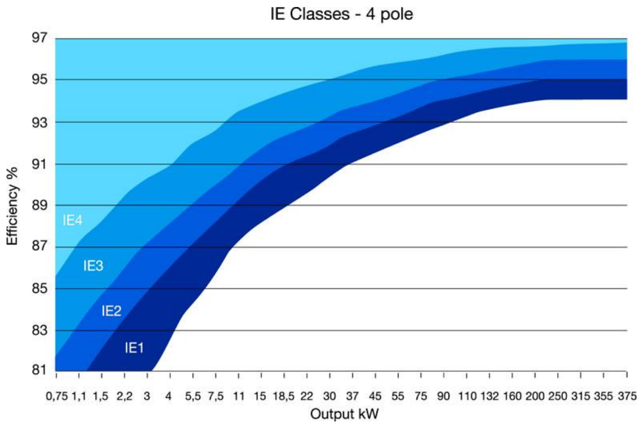

Figure 1: IE efficiency classes for 4-pole 50 Hz motors

Fig.1 indicates the efficiency classes defined in IEC 60034-30 for 50-Hz four-pole three-phase induction motors. To increase the efficiency, several methods have been put forward earlier. The core-stack-lengthening approach has been discussed in [3] and [4]. In [3], no-tooling cost method is discussed, and it was investigated that it can be used to increase the efficiency of the motors by annealing the stator core and using the copper bars in rotor. The authors of [4] used both the finite-element and the analytical approach to investigate the axial core lengthening of the motor.

In [5] and [6], die-cast copper rotor technology, optimization of core length and rotor geometry is presented in order to increase the efficiency and to reduce rotor and stray load losses.

Nevertheless, such methods increase cost and production time. So, single layer winding design for premium efficiency motor is presented in this paper in order to reduce losses and increase the efficiency. It is easy to be carried out and will not increase costs obviously. The motor is designed with the single layer winding as per the design catalogues. Its performance is calculated with the help of Siemens software. The prototype is manufactured and its test results are compared with the existing motor of same rating having double layer winding.

Table 1: Motor Parameters

Parameters	Values
Stator Diameter (D)	180 mm
Packet Length (L)	170 mm
Frequency (f)	50 Hz
Voltage (U)	415 V
Rated Current (I)	27 A
Rated Power (P)	15 kW
Rated Torque (T)	97.2 Nm
Poles	4
Rotor Diameter	178.95 mm

Improvement in the type of armature winding

A. Stator Winding Types

Basically, there are two physical types of stator windings. These are double-layer windings and single-layer windings.

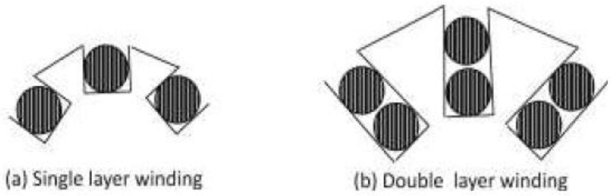

Figure 2: Winding Configurations

In single layer winding, the complete slot is containing only one coil side whereas in double layer winding, two coil sides are placed in single slot.

B. Improvement in the Winding Dimensions and Configuration

The dimensions and configuration of armature winding should be improved to increase the efficiency. The cross-sectional area of copper wires is increased to reduce the resistance of armature winding. However, this should be done precisely, as it will also influence the starting current and slot fill factor. The parameters of the optimized motor are shown in Table 2.

Table 2: Optimized Winding Parameters

Winding Parameters	Existing Double Layer	Optimized Single Layer
No. of Poles	4	4
No. of Slots	36	36
Slots/Pole/Phase	3	3
Conductors/Slot	2*14 (28)	27
No. of Wires	7	6
No. of Turns/Phase	168	162
Bare diameter	0.90 mm	1.00 mm
Area (bare)	0.636 mm^2	0.785 mm^2
Coil Pitch	7/9	9/9
Coil Span	1-10,2-9,3-8	1-10,2-9;11-18
Length of mid overhang	210 mm	215 mm
Winding Factor	0.90	0.95
Fill Factor	0.82	0.78

Motor test results

Following tests are carried out on optimized motor:

A. No load test
B. No load Characteristics
C. Short-circuit test
D. Temperature rise test
E. Winding Resistance Measurement
F. Load Characteristics

A. No Load test

Table 3: No Load test

Measured values						Cal. values acc. To (IEC 60034-2-1)	
f Hz	U V	I A	P_1 kW	Cos Φ	R Ω	% $(U/U_N)^2$	Pc kW
50	456.6	15.34	0.674	0.06	0.398	1.21	0.533
50	415.0	11.03	0.428	0.05	0.398	1.00	0.356
50	373.5	8.56	0.320	0.06	0.398	0.81	0.276

B. No Load Characteristics

No load characteristics are shown in fig. 3 which is generated by plotting P and I with respect to $(U/U_N)^2$. The friction losses P_{fw} at rated voltage are determined from the no-load characteristic by extrapolating the graph to zero volt and the constant losses are calculated by subtracting P_{fw} from P_c. Thus, the friction losses are found out to be 0.057 kW and iron losses are 0.298 kW

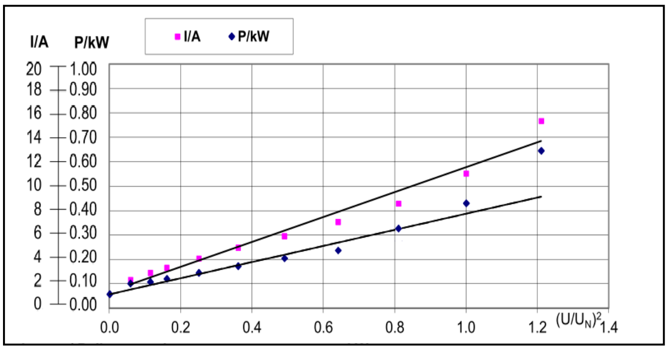

Figure 3: No-Load Characteristics

C. Short Circuit Test

Table 4: Short Circuit Test

Frequency Hz	Current A	Voltage V	Power Input kW	Power Factor
50.0	27.07	89.8	1.101	0.26

D. Temperature Rise Test

Table 5: Temperature Rise Test

Single Layer	Time (hrs.)	Temp. rise (^{0}C)
Stator Winding	4.6	54.5

E. Winding Resistance Measurement

Table 6: Winding Resistance Measurement

Resistance	Phase	Measured at 31.1 deg.
Stator Winding	U1-V1	0.32120 Ω
	U1-W1	0.32130 Ω
	V1-W1	0.32100 Ω

F. Load Characteristics

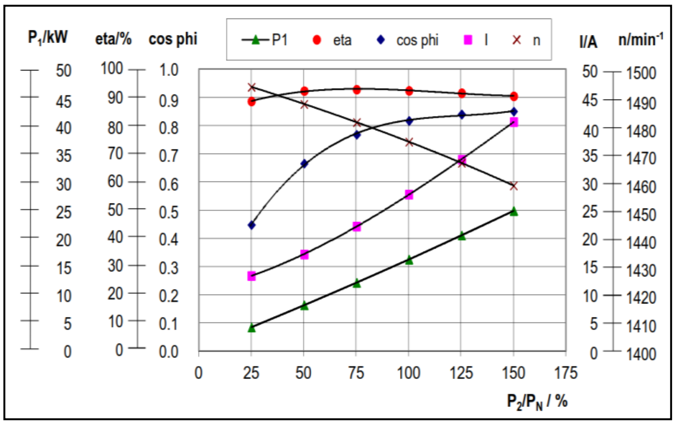

Figure 4: Load Characteristics

Table 7: Load Data

Measured values								Calc. Values				
f Hz	U V	I A	P_1 kW	Cos Φ	n min^{-1}	T Nm	R Ω	P_2 kW	P_T kW	P_2/P_N %	η %	S
50.0	415.2	40.66	24.905	0.85	1458.7	147.3	0.39829	22.530	2.375	150.20	90.46	2.729
50.0	415.0	34.02	20.546	0.84	1466.7	122.2	0.39829	18.808	1.738	125.39	91.54	2.195
50.0	415.2	27.79	16.283	0.83	1474.2	97.1	0.39829	15.042	1.241	100.28	92.38	1.695
50.0	415.2	22.15	12.172	0.77	1481.2	72.5	0.39829	11.295	0.877	75.30	92.80	1.229
50.0	415.0	17.20	8.173	0.67	1487.6	48.1	0.39829	7.545	0.628	50.30	92.32	0.801
50.0	415.4	13.38	4.255	0.45	1493.7	23.9	0.39829	3.771	0.484	25.14	88.62	0.395

Table 8: Calculations of Individual Losses

Calculation acc. to IEC 60034-2-1									
P_2/P_N %	P_{fw} kW	P_{fe} kW	P_s kW	P_r kW	P_{LL} kW	P_T kW	P_1 kW	P_2 kW	η %
150.20	0.057	0.269	0.988	0.645	0.415	2.375	24.905	22.530	90.46
125.39	0.057	0.273	0.692	0.430	0.286	1.738	20.546	18.808	91.54
100.28	0.057	0.278	0.462	0.263	0.181	1.241	16.283	15.042	92.38
75.30	0.057	0.283	0.293	0.143	0.101	0.877	12.172	11.295	92.80
50.30	0.057	0.288	0.177	0.062	0.044	0.628	8.173	7.545	92.32
25.14	0.057	0.294	0.107	0.015	0.011	0.484	4.255	3.771	88.62

Performance comparison and analysis

Losses comparison of single layer motor and double layer motor is shown in figure 5. It is observed that the losses in optimized single layer motor are less than existing double layer motor. Figure 6 shows the efficiency comparison of optimized IE3 motor with double layer motor. We can observe the improvement in the efficiency of optimized motor and it attained the minimum efficiency level of IE3 class. The efficiency of single layer optimized motor is more than the double layer motor at rated and extended range of loading conditions.

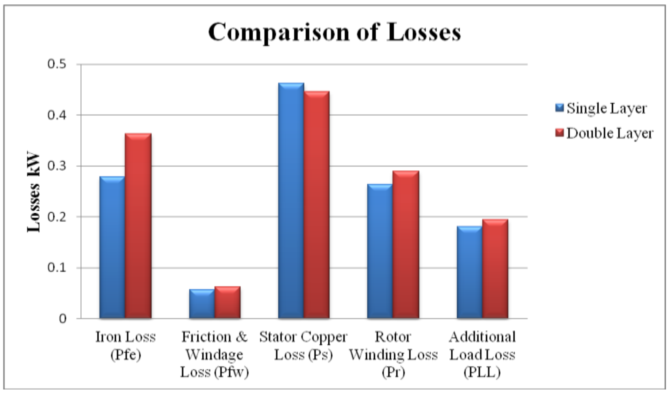

Figure 5: Comparison of losses between single layer and double layer motor

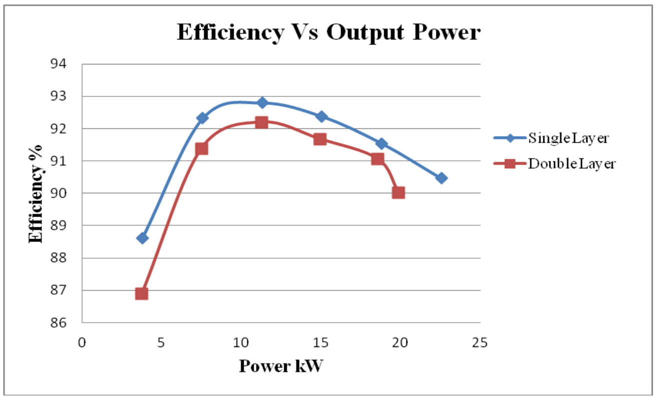

Figure 6: Efficiency versus Output Power Comparison

Table 9: Performance Comparison of Optimized Motor with Double Layer Motor at Rated Conditions

Parameters	Double Layer Motor	Optimized Single Layer Motor
Stator Current (A)	27.13	27.79
Iron Loss (kW)	0.362	0.278
Friction and Windage Loss (kW)	0.062	0.057
Stator Copper Loss (kW)	0.445	0.462
Rotor Winding Loss (kW)	0.289	0.263
Additional Load Loss (kW)	0.194	0.181
Total Loss (kW)	1.352	1.241
Efficiency (%)	91.68	92.38
Mechanical Torque (Nm)	97.11	97.1
Temperature Rise (^{0}C)	58.1	54.5
Power Factor	0.83	0.83
Slip (%)	1.60	1.695

Fig. 7 shows the torque speed characteristics of single layer and double layer motor. It can be observed that there is a little reduction in the breakdown torque but the starting torque is significantly more than double layer motor. This prototype was tested at Siemens Advance Motor Testing Centre.

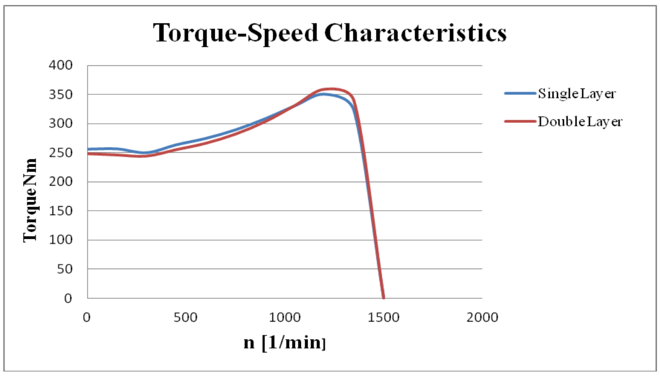

Figure 7: Comparison of Torque-Speed Characteristics

Table 10: Cost and Time Saving Analysis

Parameters	Double Layer	Single Layer	Base Rate	Unit	Cost and Time Saving
Diameter	180	180	-	mm	-
Length	170	170		mm	-
E-steel Weight	81.5	81.5	58	Rs/kg	-
Strands	7/0.90	6/1.00	-	-	
Copper Weight	15.181	15.695	450	Rs/kg	-3.38%
Aluminium	0.216	0.216	140	Rs/kg	-
Winding Time	3	1.7	-	Hours	1.3
Production Time	26	21	-	Hours	5
Saving in Labour Cost					**23.56%**
Total Cost Saving					**20.18%**

CONCLUSION

In this paper, a single layer winding is designed for 15 kW, 4-pole premium efficiency induction motor as a solution for cost reduction and improving the efficiency. The main process modifications include single layer stator winding, coil pitch, strands, cross-sectional area, number of turns, overhang length. The dimensions of the optimized motor are kept same as that of the existing double layer motor. As a consequence, the production time as well as the cost of the motor is reduced at a greater extent.

According to IEC 60034-30-1, the efficiency level of IE3 motor should be 92.1%. The efficiency attained by the optimized motor is 92.38%. Hence, the required efficiency level is attained.

Efficiency could be improved further by using copper die-cast rotors, increasing the core length, changing the stator slot geometry but this was not done as it will increase the cost and also the production time of motor.

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