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Design and Optimization of Three Phase Induction Motor using Genetic Algorithm

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ABSTRACT

With the increase of modernized equipments in our day-to-day life, demand for energy also increases, therefore to solve this energy crisis many new efforts have been made by exploiting renewable sources for obtaining energy or by improving the operating efficiency of devices requiring bulk consumption of electric energy. The design of induction motor using simplified method of Genetic algorithm is carried out with the objective of maximizing efficiency.

1. INTRODUCTION

Induction motors[1] have many applications in the industries because of their low cost maintenance and robustness. Induction motors are used in very large numbers in a variety of applications. Design may be defined as a creative physical realization of theoretical concepts. Engineering design is application of science, technology and invention to produce machines to perform specified tasks with optimum economy and efficiency. Engineering is the economical application of scientific principles to practical design problems. If the items of cost and durability are omitted from a problem, the results obtained have no engineering value.

The problem of design and manufacture of electric machinery is to build, as economically as possible, a machine which fulfils a certain set of specifications and guarantees. Thus design is subordinated to the question of economic manufacture. In the past, the design of induction motor has been attempted for achieving better performance characteristics or reducing the cost. Any significant improvement in the operating efficiency[3] of induction motor helps into energy conservation.

1.1 Introduction to Genetic Algorithm

Genetic algorithm is one of the optimization methods inspired by the natural genetics. Genetic algorithm is a directed random search technique that is widely applied in optimization problems. This is especially useful for complex optimization problems where the number of parameters is large and the analytical global solutions are difficult to obtain. Due to GA's capability of finding the global optimum in the wide range of the functions, it has numerous applications in the optimization problems. In this method the use of random but intelligent search in a predefined area, the parameters of the proposed function lead to their optimum values. This method is a conventional procedure to solve nonlinear equations. In the Genetic algorithm the search of the optimal solution is basically performed proceeding from one group (population) of possible points in the search space to another, according to procedures that resemble those of natural selection and genetics and designed such as to steer the search towards better solutions.

The flow chart for design of three phase induction motor [1] which is shown in Figure 1:

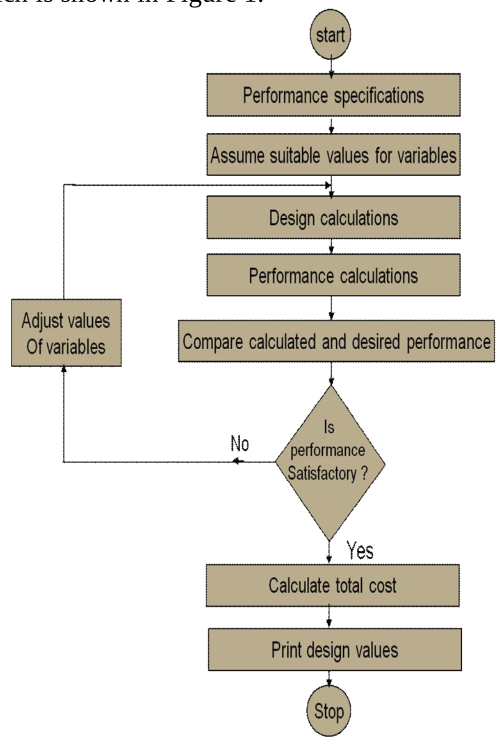


Figure 1: Flow chart for design of three phase induction motor

In this dissertation work an attempt has been made to optimize the design of induction motor using Genetic Algorithm with the objective of maximizing the efficiency.

2. RESULTS AND DISCUSSIONS

2.1 The optimization problem:

The design optimization of induction motor can be expressed mathematically as follows.

Find $X(x_1, x_2, x_3, x_4, x_5, x_6, \ldots\ldots\ldots\ldots x_1)$

Such that F(X) is maximum

Where $X(x_1, x_2, x_3, x_4, x_5, x_6, \ldots\ldots\ldots\ldots x_1)$ is the set of independent variables.

F(X) is the objective function.

The eight basic variables with their upper and lower bounds are as follows:

1. Air gap flux density $0.3 \leq x_1 \leq 0.65$ wb/m^2
2. Ampere conductors $5000 \leq x_2 \leq 45000$ A/m
3. Stator core depth $0.0175 \leq x_3 \leq 0.026$ m
4. Stator winding current density $3 \leq x_4 \leq 8$ A/mm^2
5. Rotor winding current density $4 \leq x_5 \leq 10$ A/mm^2
6. Air gap length $0.00035 \leq x_6 \leq 0.00070$ m
7. Stator slot depth to width ratio $1.5 \leq x_7 \leq 4.5$
8. Rotor slot depth to width ratio $1.0 \leq x_8 \leq 2.0$

The objective function to be maximized is F(X). The following constraints are imposed on the design optimization problem.

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

2.2 Optimization using Genetic Algorithm Toolbox:

To open the tool, enter

gatool

at the MATLAB prompt. This opens the Genetic Algorithm Tool, as shown in the figure 2

Fitness function is **Efficiency**
Number of variables = **8** i.e. x_1 to x_8
Population = **100**
Initial range = [**0.3 50000.0175340.000351.51.0; 0.65 45000 0.02608100.000704.52.0**]

Enter these values in Genetic Algorithm Toolbox and start the genetic algorithm, then we will get optimum values of variables of a induction motor.

In this paper, to attain optimum results, squirrel cage induction motor[1] with six different ratings has been considered which are mentioned as below:

1. 1KW induction motor (efficiency-0.8, pf-0.825)
2. 2.2KW induction motor(efficiency-0.8, pf-0.825)
3. 5KW induction motor(efficiency-0.86, pf-0.86)
4. 6KW induction motor(efficiency-0.83, pf-0.84)
5. 8KW induction motor(efficiency-0.86, pf-0.87)
6. 10KW induction motor(efficiency-0.86, pf-0.87)

The optimum values of X1 to X8 are calculated by using Genetic Algorithm and are shown in Table 1.

Table 1: Calculated optimum values of different ratings of 3-phase induction motor

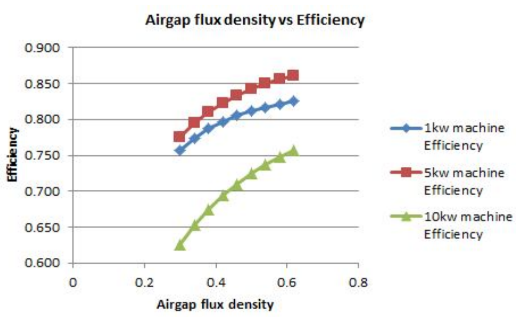
Optimum values	**Three Phase Induction Motor Ratings**					
	1KW	2.2KW	5KW	6KW	8KW	10KW
X1	0.585	0.585	0.481	0.584	0.452	0.439
X2	11487.2	11487.2	5509.7	19941.6	34343.9	23262.6
X3	0.023	0.023	0.019	0.022	0.028	0.0237
X4	3.298	3.298	6.544	6.317	7.28	4.0202
X5	6.537	6.537	7.123	8.492	4.057	8.2258
X6	0.001	0.001	0.0015	0.003	0.0045	0.007
X7	4.052	4.052	1.704	3.774	3.766	2.3343
X8	1.559	1.559	1.411	1.957	1.377	1.277
Fitness Function value	0.8055	0.8331	0.8245	0.8345	0.8246	0.8245

3. APPENDIX

Table 2: Airgap flux density vs Efficiency

Air gap flux density	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62
1kw machine Efficiency	0.757	0.774	0.787	0.797	0.805	0.812	0.817	0.822	0.826
5kw machine Efficiency	0.775	0.795	0.811	0.823	0.834	0.842	0.850	0.856	0.861
10kw machine Efficiency	0.626	0.653	0.675	0.694	0.710	0.724	0.737	0.748	0.758

Figure 2: Airgap flux density vs Efficiency



Summary of Table 2 and Figure 2

With the increase in Airgap flux density Efficiency increases for 1KW, 5KW and 10KW Machine.

Table 3: Airgap flux density vs Stator turns per phase

Air gap flux density	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62
1kw machine Stator turns per phase	777.47	715.23	664.11	621.25	584.69	553.08	525.41	500.97	479.18
5kw machine Stator turns per phase	443.7	408.18	379.18	354.55	333.68	315.64	299.85	285.9	273.47
10kw machine Stator turns per phase	327.25	301.05	279.54	261.49	246.11	232.80	221.16	210.87	201.70

Figure 3: Airgap flux density vs Stator turns per phase

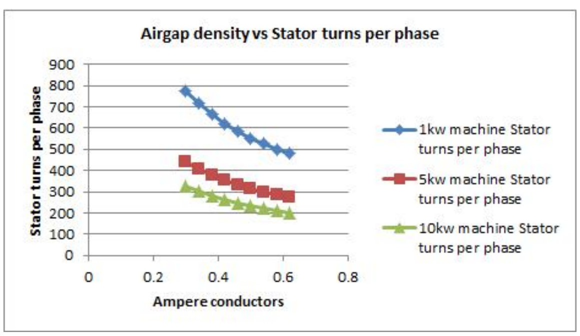


Table 4: Ampere conductors vs Machine Efficiency

Ampere Conductors	5000	10000	15000	20000	25000	30000	35000	40000	45000
1kw machine Efficiency	0.7775	0.7611	0.75	0.7414	0.7343	0.7281	0.7227	0.7179	0.7134
5kw machine Efficiency	0.8539	0.836	0.8234	0.8133	0.8047	0.7972	0.7904	0.7842	0.7786
10kw machine Efficiency	0.6256	0.6526	0.675	0.694	0.7102	0.7243	0.7367	0.7477	0.7575

Figure 4: Ampere Conductors vs Efficiency

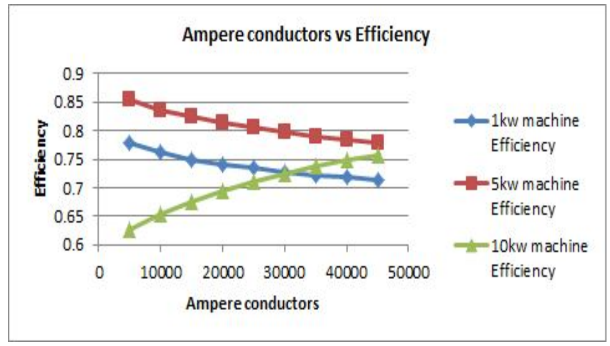


Table 5: Ampere Conductors vs Stator turns per phase

Ampere Conductors	5000	10000	15000	20000	25000	30000	35000	40000	45000
1kw machine Stator turns per phase	265.2811	334.2332	382.6015	421.1075	453.6243	482.0477	507.4644	530.5621	551.8069
5kw machine Stator turns per phase	212.0225	267.1316	305.7893	336.5647	362.5534	385.5534	405.5844	424.045	441.0246
10kw machine Stator turns per phase	327.2506	301.0523	279.5367	261.494	246.1063	232.7991	221.156	210.8673	201.6973

Figure 5: Ampere conductors vs Stator turns per phase

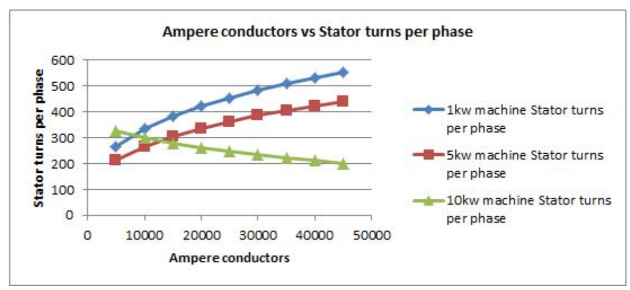


Table 6: Airgap flux density vs Stator conductors per slot

Air gap flux density in wb/m^2	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62
1kw motor Stator conductors per slot	194.36	178.8	166.02	155.31	146.17	138.27	131.35	125.24	119.79
5kw motor Stator conductors per slot	65.62	60.37	56.05	52.44	49.35	46.68	44.35	42.28	40.44
10kw motor Stator conductors per slot	54.54	50.18	46.59	43.58	41.02	38.80	36.86	35.14	33.62

Figure 6: Airgap Flux density vs Stator conductors per slot

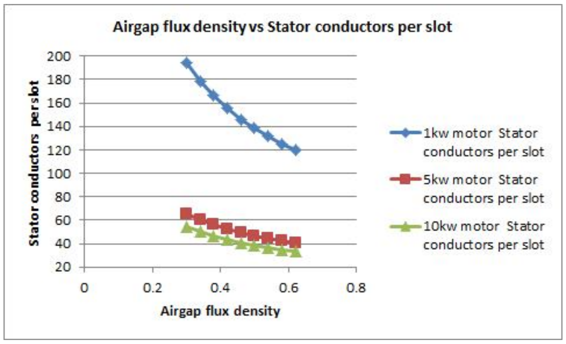


Table 7: Airgap flux density vs Flux density in stator teeth

Air gap flux density in wb/m^2	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62
1 kw motor flux density in stator teeth wb/m^2	0.60	0.65	0.70	0.75	0.80	0.84	0.89	0.93	0.97
5 kw motor flux density in stator teeth wb/m^2	1.18	1.29	1.39	1.48	1.57	1.66	1.75	1.84	1.92
10kw motor flux density in stator teeth wb/m^2	1.94	2.10	2.27	2.42	2.57	2.72	2.86	3.00	3.14

Figure 7: Airgap flux density vs Motor flux density in stator teeth

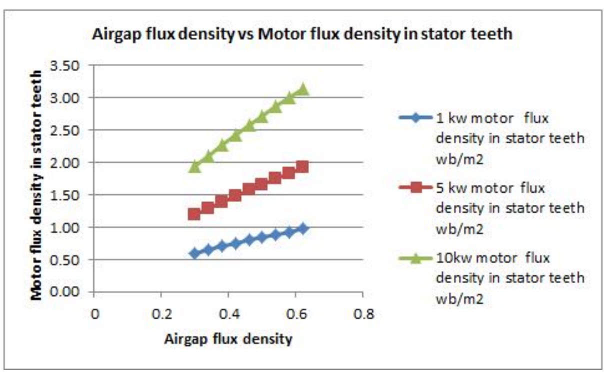


Table 8: Airgap flux density vs End ring current in Amps

Air gap flux density in wb/m^2	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62
1kw motor End ring current in Amps	356.67	328.12	304.67	285	268.23	253.73	241.04	229.82	219.83
5kw motor End ring current in Amps	560.13	515.29	478.46	447.58	421.24	398.46	378.53	360.92	345.23
10 kw end ring current in Amps	931.035	856.5	795.288	743.956	700.178	662.318	629.194	599.922	573.833

Figure 8: Airgap flux density vs end ring current

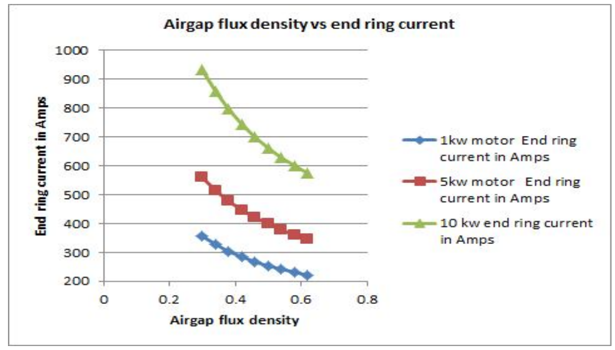


Table 9: Airgap flux density vs Copper loss in End rings

Air gap flux density in wb/m^2	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62
1kw motor copper loss in end rings watts	5.64	4.23	3.27	2.59	2.1	1.72	1.44	1.21	1.03
5kw motor copper loss in end rings watts	56.64	43.32	34.14	27.57	22.7	19.01	16.14	13.86	12.03
10kw motor copper loss in end rings watts	200.82	154.11	121.87	98.72	81.54	68.46	58.28	50.20	43.69

Figure 9: Airgap flux density vs Copper loss in end rings

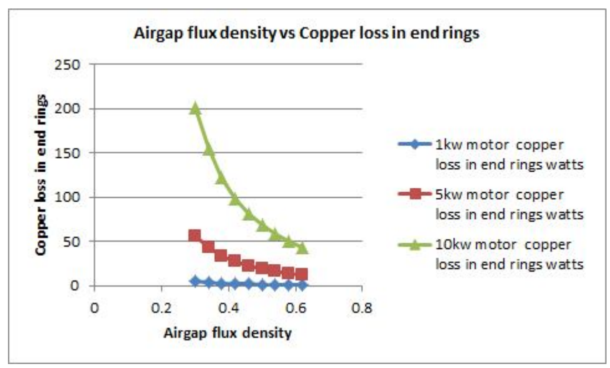


Table 10: Airgap flux density vs Slot leakage reactance

Air gap flux density in wb/m^2	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62
1kw motor Slot leakage reactance in Ω	33.44	27.15	22.55	19.09	16.4	14.27	12.55	11.14	9.97
5kw motor Slot leakage reactance in Ω	6.26	5.08	4.22	3.57	3.07	2.67	2.35	2.08	1.86
10kw motor Slot leakage reactance in Ω	5.12	4.16	3.45	2.92	2.51	2.19	1.92	1.71	1.53

Figure 10: Airgap flux density vs Slot leakage reactance

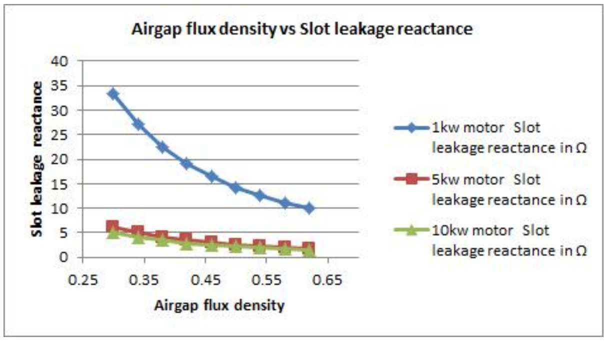


Table 11: Ampere Conductors vs Stator conductors per slot

Ampere Conductors A/m	5000	10000	15000	20000	25000	30000	35000	40000	45000
1kw machine Stator conductors per slot	66.32	83.55	95.65	105.27	113.4	120.51	126.86	132.64	137.95
5kw machine Stator conductors per slot	35.33	44.52	50.96	56.09	60.42	64.21	67.59	70.67	73.5
10kw machine Stator conductors per slot	54.54	50.18	46.59	43.58	41.02	38.80	36.86	35.14	35.62

Figure 11: Ampere conductors A/m vs Stator conductors per slot

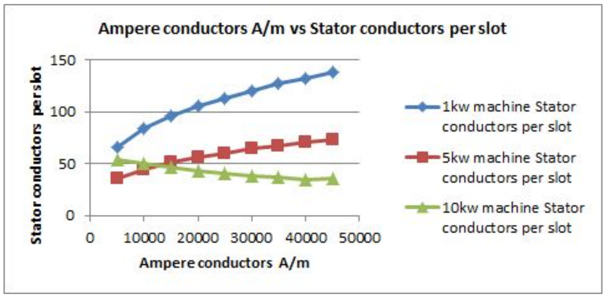


Table 12: Ampere Conductors vs Slot Area

Ampere Conductors A/m	5000	10000	15000	20000	25000	30000	35000	40000	45000
1kw machine Area of slot mm^2	117.52	148.06	169.49	186.55	200.96	213.55	224.81	235.04	244.45
5kw machine Area of slot mm^2	62.61	78.89	90.31	99.4	107.07	113.78	119.78	125.23	130.25
10kw machine Area of slot mm^2	96.65	88.91	82.56	77.23	72.69	68.76	65.32	62.28	59.57

Figure 12: Ampere conductors A/m vs Slot area in sqmm

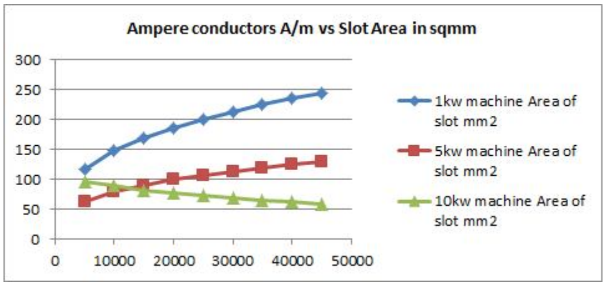


Table 13: Ampere Conductors vs Rotor bar current

Ampere Conductors A/m	5000	10000	15000	20000	25000	30000	35000	40000	45000
1kw machine rotor bar current in A	69.51	87.58	100.25	110.34	118.86	126.31	132.97	139.03	144.59
5kw machine rotor bar current in A	234.92	295.98	338.81	372.91	401.71	426.88	449.38	469.84	488.65
10kw machine rotor bar current in A	523.32	481.42	447.02	418.16	393.56	372.28	353.66	337.20	322.54

Figure 13: Ampere conductors A/m vs Rotor bar current in Amps

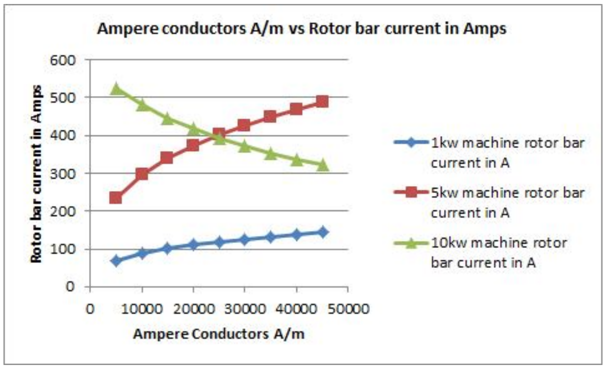


Figure 14: GA Tool bar view

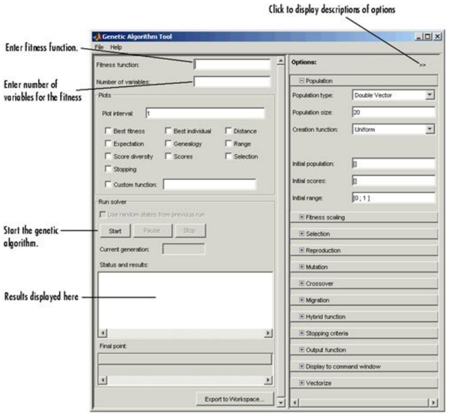


Figure 15: 1KW Induction motor results

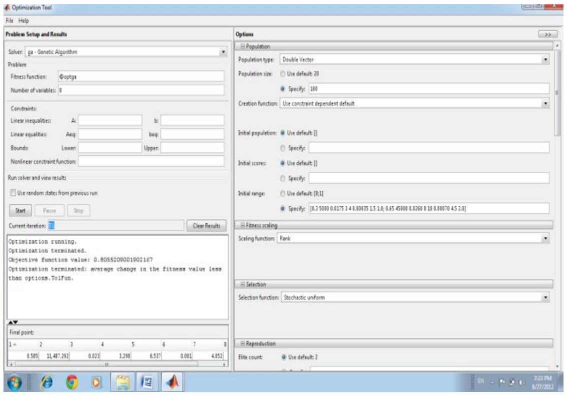


Figure 16: 2.2 KW results

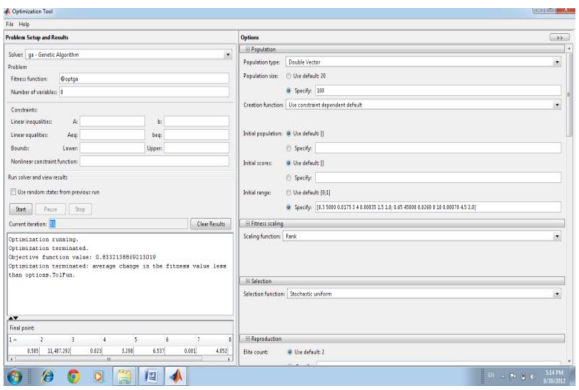


Figure 17: 5KW results

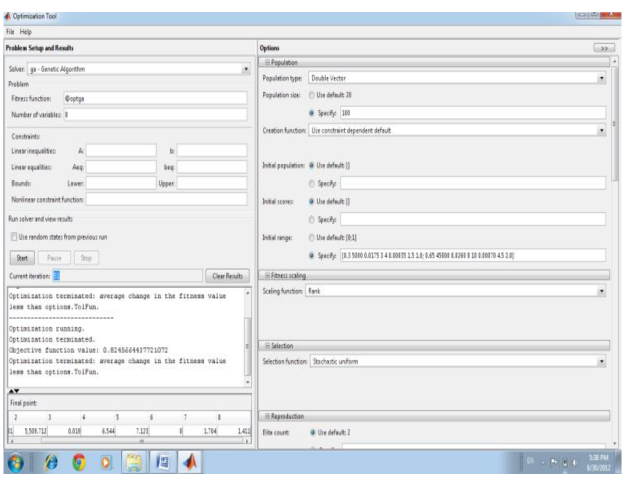


Figure : 6KW results

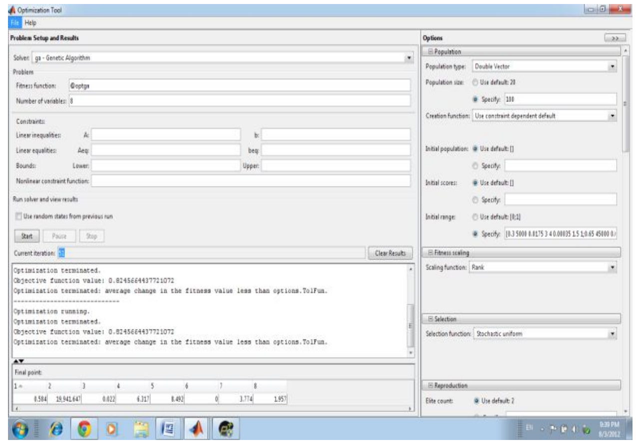


Figure : 8KW results

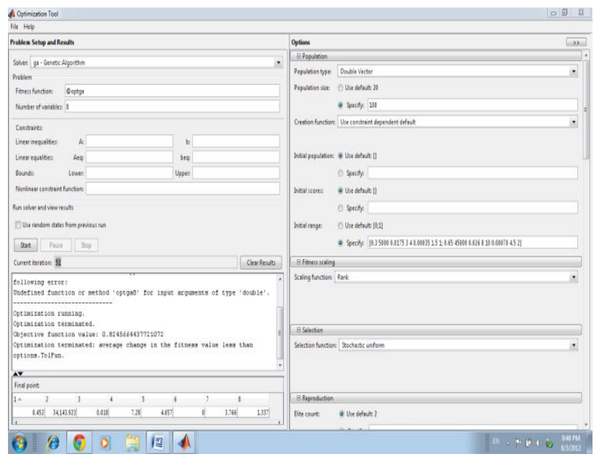
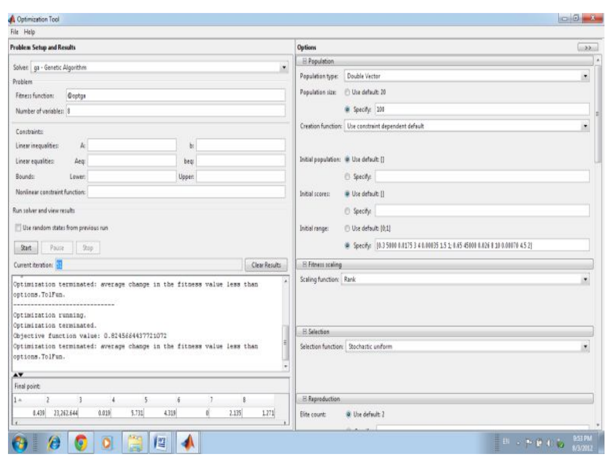


Figure : 10KW results



4. CONCLUSION

The main aim of the present investigation was to optimize the design of the three phase squirrel cage induction motor using MATLAB. In this dissertation work we developed a program for design of three phase induction motor. By using this program we can get the design sheet of any rating of induction motor[6]. This has been successfully achieved for a typical 3-ph, (1kw, 2.2kw, 5kw, 6kw, 8kw, 10kw) 400v, 3-phase, 50 Hz, 1500 synchronous r.p.m. squirrel cage induction motor. The machine is to be started by a star delta starter.

In this dissertation work, the optimum values of variables are taken by using genetic algorithm[4] where the objective function is efficiency. Further, for different rating of machines (i.e. 1kw, 2.2kw, 5kw, 6kw, 8kw, 10kw) by varying the airgap flux density the changes in efficiency has been observed. Similarly, for different rating of machines (i.e. 1kw, 2.2kw, 5kw, 6kw, 8kw, 10kw) by varying the ampere conductors the changes in efficiency has been observed.
Results of this investigation have clearly demonstrated that the constraints can easily be incorporated in the design optimization of the induction motor[1]. This will make the design easily acceptable to the manufacturer. This will, in fact, result in reduced cost of manufacturing the machine. However, it is clear that this will, indeed, make the optimized design more acceptable to the manufacturers.

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