Genetic Algorithm based Parameter Identification of Three Phase Induction Motors

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ABSTRACT

Induction motors are the work horse of the modern industry. A dynamical model of a 3-Φ induction motor is developed with an aim of parameter identification. Genetic algorithm based approach is used to demonstrate the concept of estimating the motor parameters from the experimental data. Parameter identification of the motor is achieved and the speed torque characteristics of the extracted motor parameters compared with the experimental data.

Keywords

3-Φ, induction motor, genetic algorithm, parameter identification

List of Symbols

A_d	Subscript d denotes direct axes quantity
A_q	Subscript q denotes quadrature axes quantity
P	Number of poles
ω_e	Electrical angular frequency
ω_{sm}	Mechanical angular frequency
ω_b	Base angular frequency
v_{qs}, v_{ds}	q and d-axis stator voltages
v_{qr}, v_{dr}	q and d-axis rotor voltages
ψ_{ij}	Flux linkages ($i = d\ or\ q, j = s\ or\ r$)
ψ_{md}, ψ_{mq}	Magnetizing flux linkages
r_s, r_r	Stator and rotor resistance
x_{ls}, x_{lr}	Stator and rotor reactance
x_m	Magnetizing reactance
L_s,L_r	Stator and rotor inductance
$i_{ds,r}, i_{qs,r}$	$d\ and\ q$-axis stator or rotor current
T_{em}	Electromechanical torque
T_{mech}	Mechanical load torque
T_{damp}	Friction damping torque
J	Rotor moment of inertia

1. INTRODUCTION

Three-phase induction motors are asynchronous speed motors, operating below the synchronous speed when in motoring mode and operating above synchronous speed when in generating mode. Induction motors are the most widely used AC machines due to their cost, reliability and performance advantages above synchronous and DC machines. Control of high-performance induction motors for industrial applications is gaining widespread research interest. To achieve induction motor control, it is very important to have an accurate mathematical model of the machine. Also determination of the mathematical model of the motor and its parameters is one of the first steps in model based synthesis of a motor controller. Hence mathematical models and methods to estimate the machine parameters is a crucial step.

Determination of parameters was done based on traditional no-load and blocked rotor tests [1]. Some of the methods used classical statistical approaches [2][3][4][5] to estimate the electromagnetic parameters of the mathematical model of the motor. Mathematical model of the motor, neglecting anisotropy of the magnetic structure, iron losses and saturation is sufficient for control applications. Genetic algorithms are a strong technique that can be used for the estimation of motor parameters by minimizing an optimization function.

In the present work, a mathematical model of a 3-Φ squirrel cage induction motor is developed to simulate the real motor characteristics. Further, the motor parameters are estimated from a set of experimental data consisting of the stator currents and the rotor speed using genetic algorithms.

2. GENETIC ALGORITHM

Genetic algorithm (GA) is a heuristic mimicking the natural evolution process and is routinely used to generate useful solutions to optimization problems [6]. In this work we use genetic algorithm to derive the PID controller parameters by optimizing the error in the DC motor angular velocity. In GA, a population of strings called chromosomes encodes the possible solutions of an optimization problem and evolves for a better solution by process of reproduction. The process of evolution starts from a population of randomly generated individuals. Optimization is achieved in generations where in each generation, the fitness function evaluates each individual in the population and multiple individuals are selected stochastically based on their fitness. These selected individuals are modified to form a new population. The algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population. The various steps in GA based optimization are detailed below.

2.1 Initialization

From the initial population few individual solutions are generated. The population is generated randomly, covering the entire range of possible solutions.

2.2 Selection

In each generation, individual solutions are selected by evaluating the fitness function and the fitter solutions have a higher probability of selection

2.3 Reproduction

Next set of population for the successive generation is generated by a process called reproduction and involves crossover (recombination) and mutation. This result in a new set of population derived from the fitter solutions of the previous population. Generally the average fitness of the population is increased as compared to the population of the previous population.

2.4 Termination

The process of optimization is halted once a termination condition is achieved. The termination condition can be either the number of generations or the solution satisfying an optimum criterion

3. MATHEMATICAL MODELING

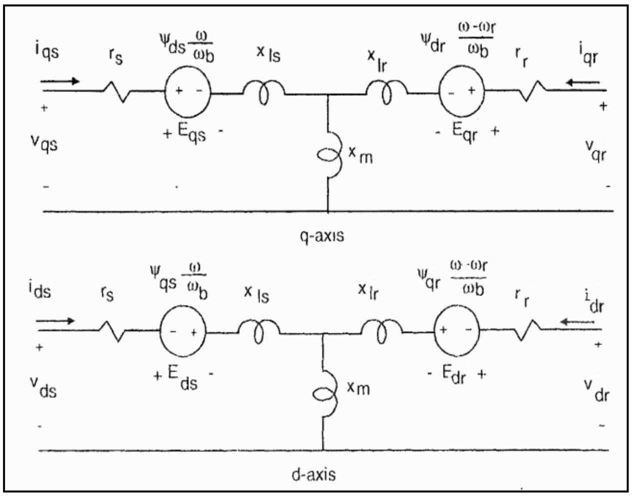

Fig 1: Equivalent Circuit of Induction Motor in dq Frame

Balanced three phase currents flowing in symmetrically placed three phase stator windings produces a rotating magnetic field. The angular frequency (w_e: electrical and w_{sm}: mechanical) of the rotating magnetic field is defined by

$$w_e = 2\pi f_e \tag{1}$$

$$w_{sm} = \frac{2w_e}{P} \tag{2}$$

Three phase quantities are converted to dq −reference frame [7] using the transformation given by Equation (3). In the present model, stationary reference frame is used. Based on the circuit described in Figure 1, the flux linkage equations for the direct and quadrature axes are given by Equation (4), Equation (5) Equation (6) and Equation (7).

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{0s} \end{bmatrix} = \begin{bmatrix} 2/3 & -1/3 & -1/3 \\ 0 & -1/\sqrt{3} & 1/\sqrt{3} \\ 1/3 & 1/3 & 1/3 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{3}$$

$$\frac{d\Psi_{qs}^s}{dt} = w_b \left\{ v_{qs}^s + \frac{r_s}{x_{ls}} \left(\Psi_{mq}^s - \Psi_{qs}^s \right) \right\} \tag{4}$$

$$\frac{d\Psi_{ds}^s}{dt} = w_b \left\{ v_{ds}^s + \frac{r_s}{x_{ls}} \left(\Psi_{md}^s - \Psi_{ds}^s \right) \right\} \tag{5}$$

$$\frac{d\Psi_{qr}^s}{dt} = w_b \left\{ v_{qr}^s - \frac{w_r}{w_b} \Psi_{dr}^s + \frac{r_r}{x_{lr}} \left(\Psi_{mq}^s - \Psi_{qr}^s \right) \right\} \tag{6}$$

$$\frac{d\Psi_{dr}^s}{dt} = w_b \left\{ v_{dr}^s - \frac{w_r}{w_b} \Psi_{qr}^s + \frac{r_r}{x_{lr}} \left(\Psi_{md}^s - \Psi_{dr}^s \right) \right\} \tag{7}$$

$$\Psi_{mq}^s = x_m \left(i_{qs}^s + i_{qr}^s \right) \tag{8}$$

$$\Psi_{md}^s = x_m \left(i_{ds}^s + i_{dr}^s \right) \tag{9}$$

The electromechanical torque is given by

$$T_{em} = \frac{3}{2} \frac{\mathrm{P}}{2} \omega_b \left(\psi_{ds}^s i_{qs}^s - \psi_{qs}^s i_{ds}^s \right) \tag{10}$$

The dynamics of the rotor is given by equation

$$J \frac{dw_{rm}}{dt} = T_{em} + T_{mech} - T_{damp} \tag{11}$$

The MATLAB/SIMULINK implementation of the above mathematical formulations is described in Section 4.

4. SIMULINK MODELING

SIMULINK is used in the modeling [8] of the mathematical formulations described in Section 3 of this paper. The model consists of basic blocks as described below.

4.1 Frame Transformations (abc to dq and dq to abc)

The blocks described in Figure 2 and Figure 3 achieve the frame transformations from rotating three phase abc-frame (axes 120° apart) to stationary dq-frame (axes 90° apart). Abc to stationary dq-frame transformation is given by Equation (3) whereas dq-frame to abc frame transformation is given by Equation (12).

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -1/2 & -\sqrt{3}/2 & 1 \\ -1/2 & \sqrt{3}/2 & 1 \end{bmatrix} \begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{0s} \end{bmatrix} \tag{12}$$

4.2 Flux Linkage Computation

The blocks described in Figure 4 and Figure 5 realizes Equations 4, Equation 5, Equation 6 and Equation 7 described in Section 3 to compute the flux linkages and there by the rtor and stator currents in the stationary d-q frame.

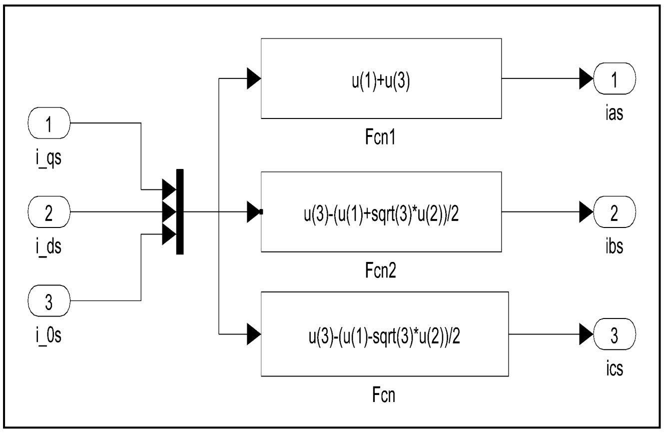

Fig 2: Frame Transformation $(abc - dq)$

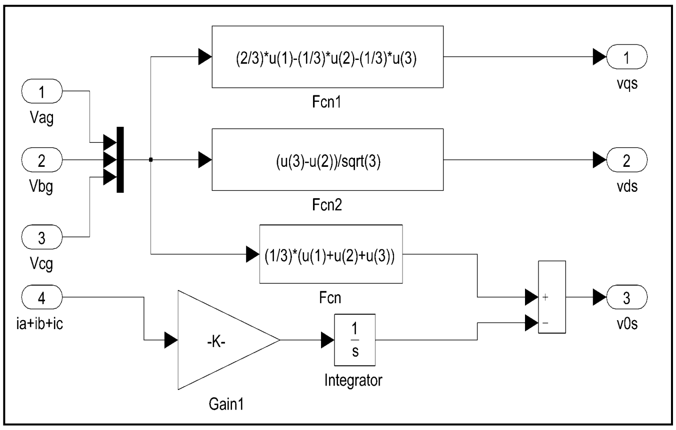

Fig 3: Frame Transformation $(dq - abc)$

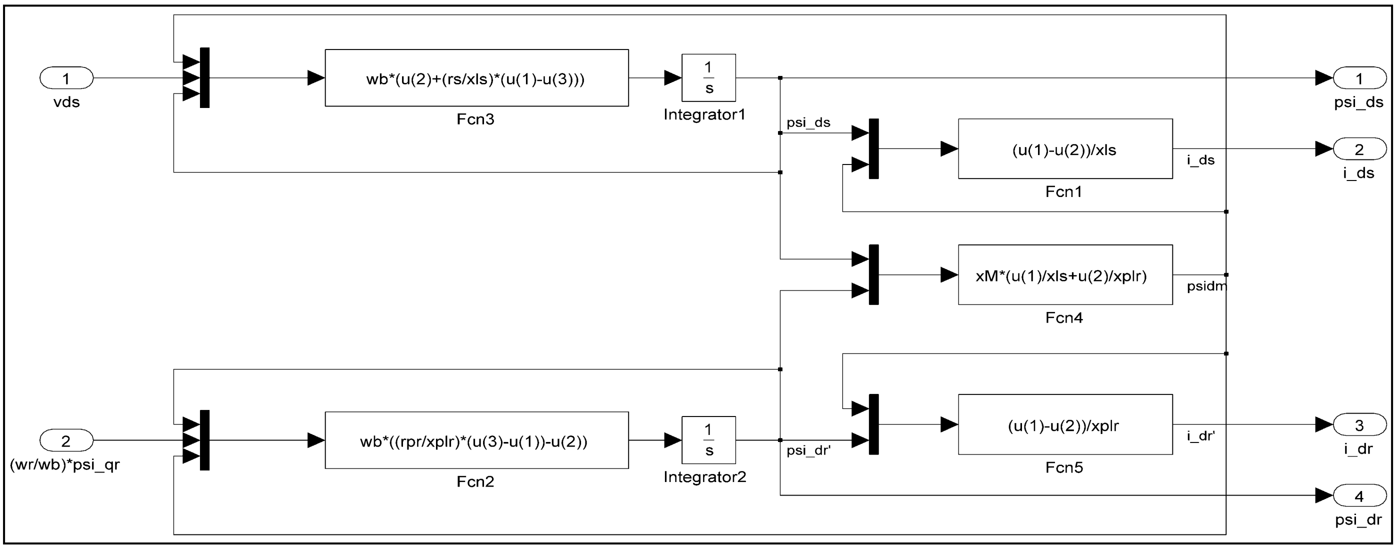

Fig 4: Flux Linkages for Direct Axis

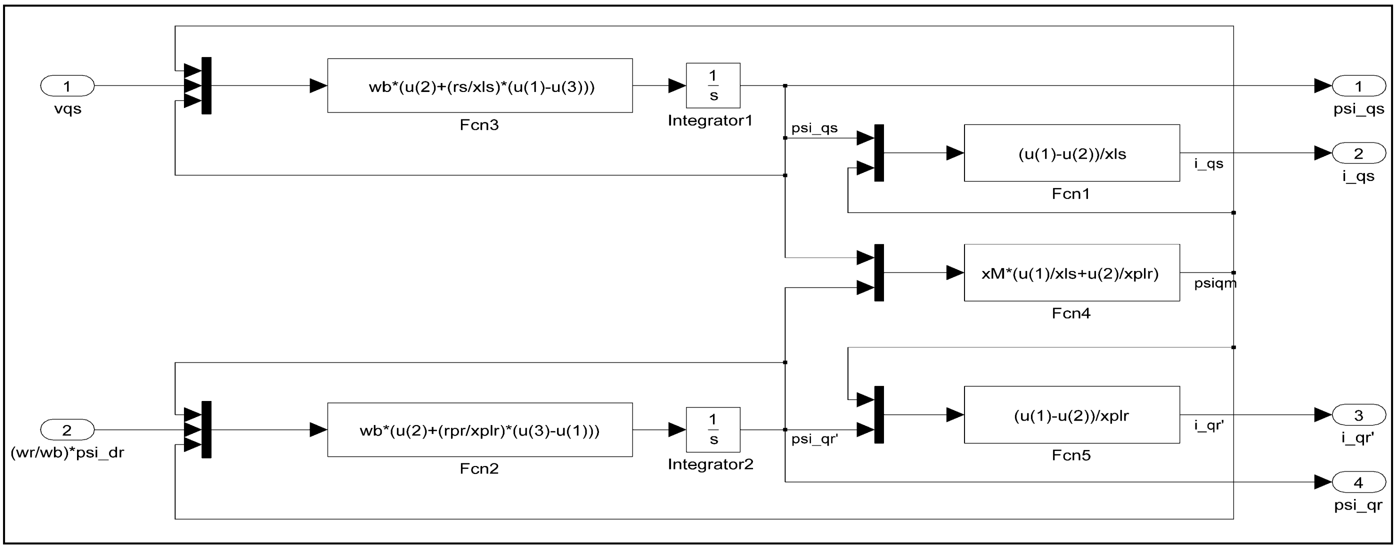

Fig 5: Flux Linkages for Quadature Axis

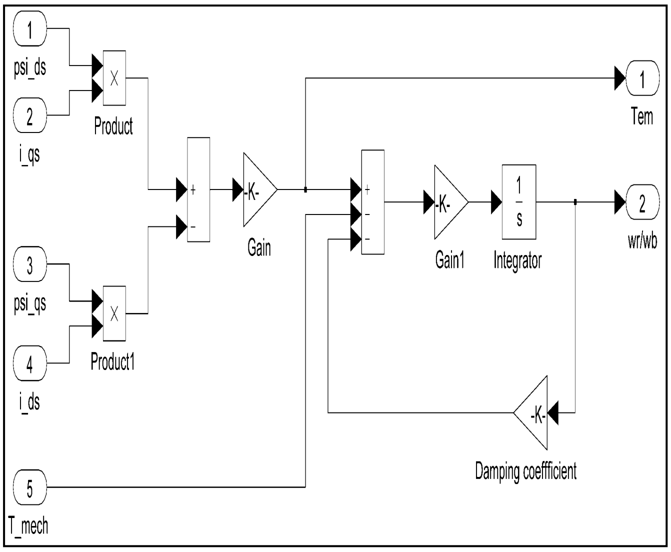

Fig 6: Rotor Dynamics for Mechanical Torque as Input

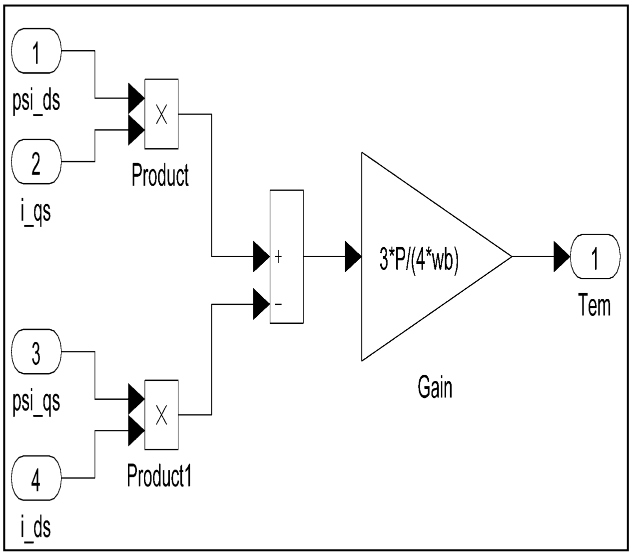

Fig 7: Rotor dynamics for rotor speed as input

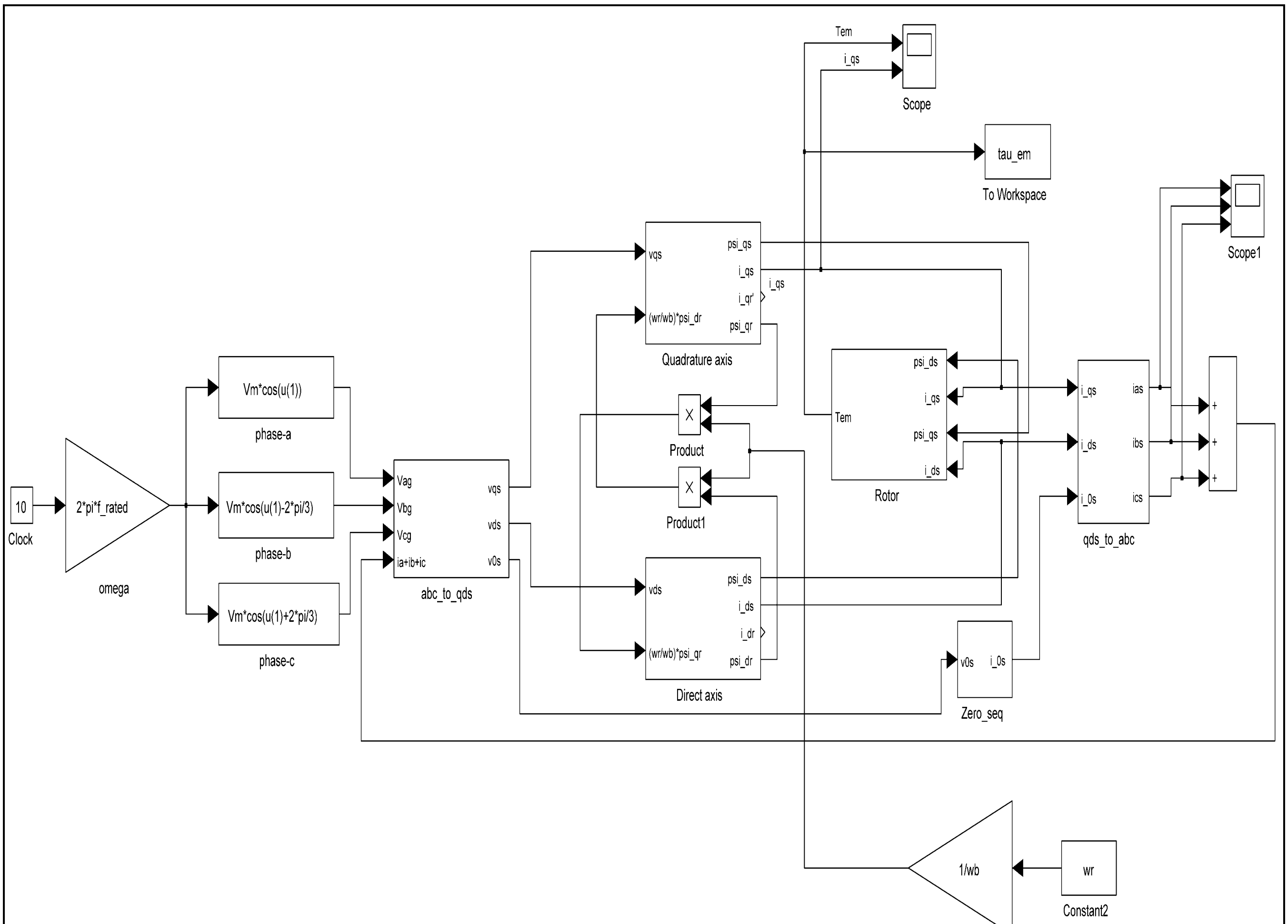

Fig 8: Induction Motor Model

4.3 Rotor dynamics

The electromechanical torque generated by the motor operating at a particular speed is given by Equation (10). When a particular rotor velocity is forced on the motor, then the rotor dynamics given by Equation (11) are neglected and only the electromechanical torque is calculated. In case when the input is the load torque T_m , then the rotor speed is computed using Equation (11). For the case when, rotor speed is forced onto the system, then Equation (11) is neglected and the electromechanical torque is calculated using Equation (10). The mathematical model developed can take the load torque or the rotor speed as the input and hence calculate T_{em} and w_r or T_{em} respectively. The modification needed is only in the rotor dynamics block as shown in Figure 6 and Figure 7. The overall block diagram of the induction motor realized using SIMULINK is given in Figure 8.

5. RESULTS AND DISCUSSION

In the work presented here, the Genetic Algorithm is used to identification of motor parameters. Experimental results are derived for a 3-phase induction motor whose parameters are tabulated in Table 1. The experimentally derived current and rotor speed values are compared with the values derived from the mathematical model and a cost function is computed. The genetic algorithm iterates over different populations of the motor parameters attempting to minimize the cost function. Cost functions tested in the present work is mentioned in Equation (13) given below. The resultant motor parameters are listed in Table 2.

$$f = \sum_j a\, f_{qj} + a f_{dj} + a f_{wj} \qquad (13)$$

Where a, b, c are the weights, and

$f_{qj} = \left| i_{qs,m} - i_{qs,e} \right|$,

$f_{dj} = \left| i_{ds,m} - i_{ds,e} \right|$ and

$f_{wj} = \left| w_{rm,m} - w_{rm,e} \right|$

Table 1.Induction Motor Parameters

Parameter	Symbol	Unit	Value
Phase	-	$nos.$	3
Poles	P	$nos.$	4
Power Rating	P_{rated}	VA	3730
Voltage Rating Rated	V_{rated}	V	460
Stator Parameters			
Resistance	r_s	Ω	1.115
Inductance	L_s	mH	5.974
Rotor Parameters			
Resistance	r_r	Ω	1.083
Inductance	L_r	mH	5.974
Mechanical Parameters			
Moment of Inertia	J	$N-m^2$	0.02
Friction coefficient	F_m	$N-ms$	5.753×10^{-3}

Figure 9 shows a comparison between speed torque characteristics of the $3-\Phi$ induction motor obtained experimentally and the one derived from the motor parameters obtained from genetic algorithm. The x-axis in the figure is the ratio of the rotor speed to the base speed. It can be verified that the generated torque at rated speed $(w_r/w_b = 1)$ is zero. For speeds less than w_b , T_{em} is positive (motoring action), while for $w_r/w_b > 1, T_{em} < 0$ (generating action). Figure 10 shows the simulated transient speed plot of the motor for different motor parameters obtained from GA optimizations.

The study demonstrates a method of obtaining the motor parameters based on the experimental data. The results validate the motor parameters derived from genetic algorithm to that with the experimental data. It is seen that, the option 1 with $a = 1, b = 1, c = 0.5$ gives the best match for the experimental data.

Table 2.Motor Parameters Derived Using Genetic Algorithm

	Cost function		
Parameter	**Option 1** $(a, b, c = 1,1,0.5)$	**Option 2** $(a, b, c = 0.15,0.15,0.7)$	**Option 3** $(a, b, c = 0.5,0.5,0)$
rs	1.0167	1.4314	1.2198
r_r	1.1291	1.3953	1.8380
L_s	0.0058	0.0075	0.0069
L_r	0.008	0.0073	0.0028
Lm	0.3545	0.2310	0.3196
J	0.0202	0.0162	0.0305
D_{omega}	0.0097	0.0013	0.0054
Generations	51	56	51

6. CONCLUSION

A mathematical model of the 3-¢ induction motor was developed for a stator referenced d-q frame. The model can simulate the dynamics of the motor and also considers the frictional damping. An approach of estimating the motor parameters using the concept of genetic algorithms was developed and validated. Cost function which is the weighted average of the stator currents and the rotor speed was evaluated and optimized for different values of motor parameters. Effect of various cost functions on the estimation was also demonstrated. The simulated speed torque characteristics from the mathematical model were compared with the experimental results and both show a good correlation validating the correctness of the mathematical model as well as the genetic algorithm approach to optimization.

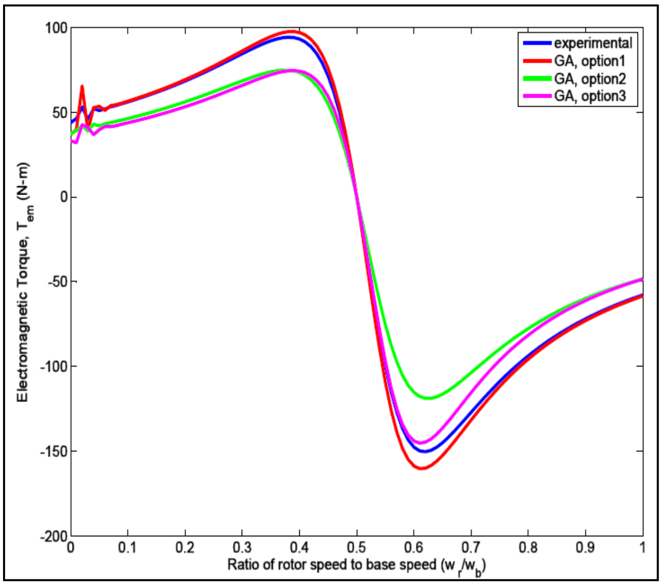

Fig 9: Speed-Torque characteristics

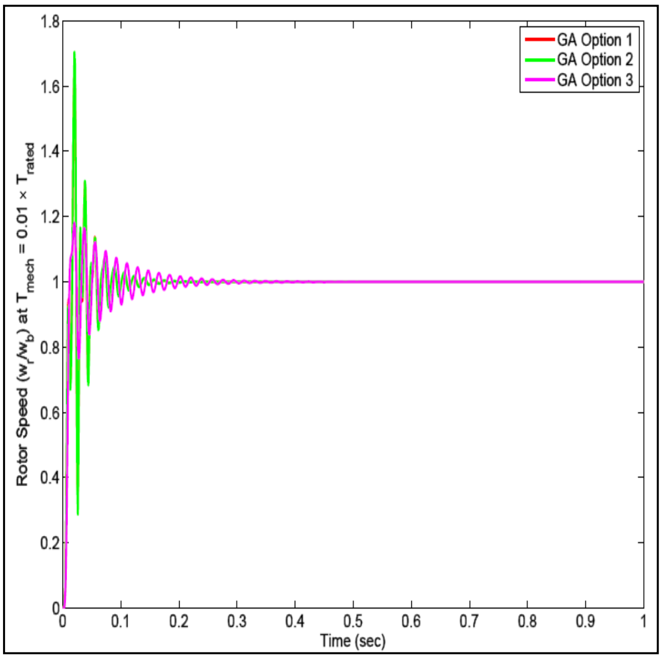

Fig 10: Rotor Speed at 1% rated load

7. ACKNOWLEDGMENTS

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