Genetic Algorithm Based Pid Tuning for a DTC Controlled Induction Motor

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***Abstract*—Direct Torque Control [1][5][10] is one of the most advanced techniques for control of induction motors, which is widely used in industries [1][3][5]. Low response time and high reliability are what it makes imperative. Although some of the DTC techniques make use of adaptive motor model for making the motor work at optimal operating point under varying machine parameters, many of them lack an adaptive PID control mechanism. This can eventually result in unwanted machine performance. Genetic Algorithm being a metaheuristic algorithm has been in use for search and optimization problems for several years [2][4][8]. It can be used to find out optimal gain values for aforementioned system. This will make the DTC more robust with respect to parameter variations. This paper examines the various aspects of using Genetic Algorithm for the same. Simulation was done in Matlab-Simulink. Direct Torque Control of induction motor was achieved with PID gain values tuned by Genetic Algorithm.**

Keywords—Direct Torque Control; Genetic Algorithm; PID Tuning; Space Vector Modulation

I. INTRODUCTION

Direct Torque Control for control of induction motors, shown in Fig. 1, has been in theory [5][10] since 1980s. The concept first introduced by Takahachi and Noguchi can be applied to synchronous drives also. Although, DTC has many advantages including good dynamic performance [11], it still has the inherent disadvantage of having torque and flux ripples due to the fact that it produces variable switching frequency which is depended on speed, load torque and hysteresis bands.

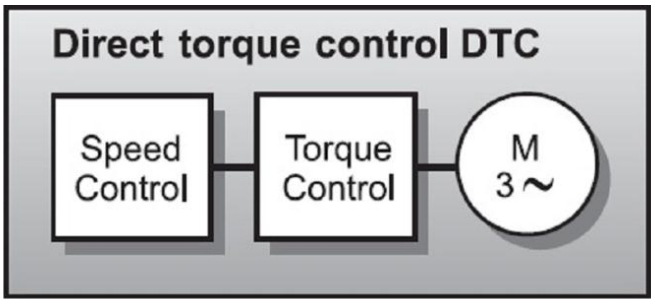

Fig. 1. Direct Torque Control of three phase AC motor [11]

DTC is now becoming popular [1][3][5][6][7] because, it is overcoming its inherent disadvantages by employing multilevel inverter and high frequency switching. The most recent research in this field includes hybridization with advanced algorithms for parameter estimation and automatic tuning of PID gain values.

Genetic algorithm is one among the evolutionary algorithms which was made popular by John Holland in 1970s. It is based on Theory of Evolution by Natural Selection proposed by Charles Darwin.

Genetic algorithms [2][4][8] as shown in Fig. 2, unlike conventional heuristic methods, can be used to solve multi model-multi dimensional global optimization problems without the need of exact mathematical relationship and it does not get stuck at local optima.

GA is thus well suited for optimizing PID gain values for a plant whose parameters can vary over time that cannot be fully predetermined, such as thermal variation of stator resistance of an induction motor.

This means, live monitoring of error for tuning the PID gain values accurately in each control loop iteration, for a plant with varying parameters, to make the control system adaptive and robust.

This paper consists of DTC controlled induction motor which is the plant (non adaptive) and the PID controller which establishes the speed-torque relationship modeled to be adaptive. The genetic algorithm is used here to find best gain values for PID controller and make it adaptive.

Thus the speed-torque relationship will be always maintained irrespective of the variations in the plant parameters. This will improve the dynamic performance of induction motor.

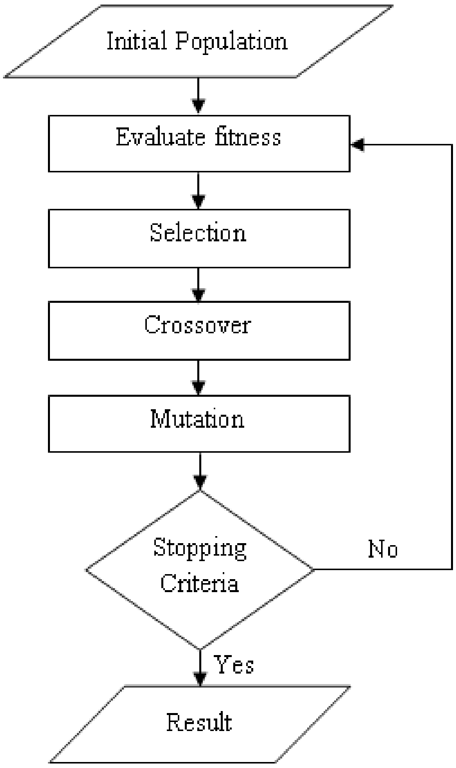

Fig. 2. Flow chart of Genectic Algorithm

II. MODELING OF INDUCTION MOTOR IN STATIONARY REFERENCE FRAME

A set of four differential equations are used in stationary reference frame model to mathematically model the induction motor. It is the simplest and one of the most used induction motor model for simulations.

$$v_{qs}^s = R_s i_{qs}^s + \frac{d}{dt}\psi_{qs}^s \quad (1)$$

$$v_{ds}^s = R_s i_{ds}^s + \frac{d}{dt}\psi_{ds}^s \quad (2)$$

$$v_{qr}^s = R_r i_{qr}^s + \frac{d}{dt}\psi_{qr}^s - \omega_r \psi_{dr}^s \quad (3)$$

$$v_{dr}^s = R_r i_{dr}^s + \frac{d}{dt}\psi_{dr}^s + \omega_r \psi_{qr}^s \quad (4)$$

Where,

$$v_{qr}^s = 0 \quad (5)$$

$$v_{dr}^s = 0 \quad (6)$$

Since, squirrel cage induction motor is used.

To find out the values of currents we make use of the equations relating current and flux given below.

$$\psi_{ds} = L_s i_{ds} + L_m i_{dr} \quad (7)$$

$$\psi_{dr} = L_m i_{ds} + L_r i_{dr} \quad (8)$$

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr} \quad (9)$$

$$\psi_{qr} = L_m i_{qs} + L_r i_{qr} \quad (10)$$

The electromagnetic torque developed is given by [5][7][9],

$$T_e = \frac{3}{2}\frac{P}{2} L_m (i_{ds} i_{qr} - i_{dr} i_{qs}) \quad (11)$$

III. SIMULATION SETTINGS

The simulation was done in Matlab-Simulink R2012b on Windows 7 (both, 32-bit) operating system. It took 5 minutes to execute the 5 seconds discrete simulation with no continuous states. The fundamental sample time used is 1 microsecond. The decimation setting of scope used to plot all the graphs in this paper is 20. The reference speed is 1250 rpm and reference torque is 0 Nm from 0 s and 2 Nm from 2.5 s.

The DSP block as shown in Fig. 5 is a Stateflow block, it is provided with gate trigger output for connection to the inverter if needed (This paper focuses only on the control part. So, inverter is simulated using a Matlab Function block and not using power electronic switches). The DSP block contains the Genetic Algorithm as shown in Fig. 5 and Fig. 6. The DTC Controlled induction motor system as shown in Fig. 7 is given as Simulink Function from inside the genetic algorithm code as shown in Fig. 6. The numbers in the Fig. 6 indicate the order of execution. State 1 initializes all variables. States 2-3-4-5-6-7 is the proportional gain tuning loop. States 8-9-10-11-12-13 is the integral gain tuning loop. States 14-15-16-17-18-19 is the derivative gain tuning loop.

The simulation has initialization function and stop function callbacks. During simulation dead time safety margin for inverter switches to completely turnoff to avoid short circuiting was not executed, since it took large time to run the simulation. It might not make significant effect on the performance of induction motor.

IV. SIMULATION

The simulation presented in this paper consists of a modified version (Fig. 7, Fig. 4, Fig. 3) of another simulation covered under Free-BSD license (see Appendix 1) which was obtained from website of Mathworks (File Exchange). Incorporation of Genetic Algorithm is the major modification.

The Genetic Algorithm as shown in Fig. 6 is firstly used to tune the proportional gain until the error is less than or equal to 10 rpm at which proportional gain tuning is halted and the integral gain tuning is commenced until error is less than or equal to 5 rpm at which integral gain tuning is halted and the derivative gain tuning is commenced until error is less than or equal to 10 rpm and greater than 1 rpm. If error is greater than 10 rpm proportional gain tuning is commenced. All tuning is halted when the error is less than or equal to 1 rpm. All variables used in the Genetic Algorithm code are initialized in State 1. States 2 to 7 is the proportional gain tuning loop. State 2 to State 4 are used to put various proportional gain values to the plant (Fig. 7) through State 3.5 (Simulink Function) and collect corresponding error values one after the other. From the collected data, State 5 does selection. State 6 does crossover, mutation and elitism. State 7 puts random proportional gain values to the population. The new population is then given to the plant again and it loops. Similar is the case with states in integral and derivative loops.

From Fig. 3 to Fig. 7, the GA PID Controller block takes the speed error and gives the reference torque. The instantaneous PID gain values generated from Genetic Algorithm is used for this purpose.

It is clearly possible to manipulate the torque and speed of an induction motor by manipulating the stator supply. The DTC Controller block as shown in Fig. 4 utilizes a hysteresis controller inside it to calculate the maximum and minimum tolerance limits. It is then fed to Switching Vector Table that selects the corresponding vector for triggering the inverter so that the rotor flux follows the stator flux. The vector number is decoded into gate trigger signals inside the Vector to Gate Map.

The Inverter Simulator simulates the magnitude and polarity of output phase voltage across the inverter output terminals.

The induction motor model is used to calculate the electromagnetic torque, stator and rotor fluxes. These data are then used to give inputs to other subsystems. Mechanical subsystem utilizes torque equation to find out actual speed. Actual speed, actual torque and actual stator flux are fed back to form the loop.

The GA PID Controller establishes a non linear relationship between torque and speed using dynamically tuned PID gain values. This dynamic tuning of PID gain values makes the DTC Controlled induction motor more robust to parameter variations.

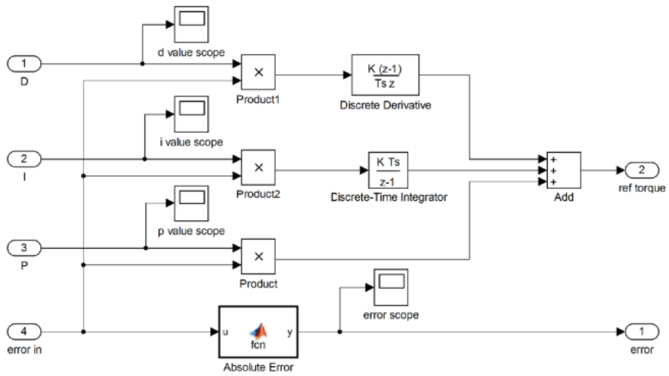

Fig. 3. GA PID Controller

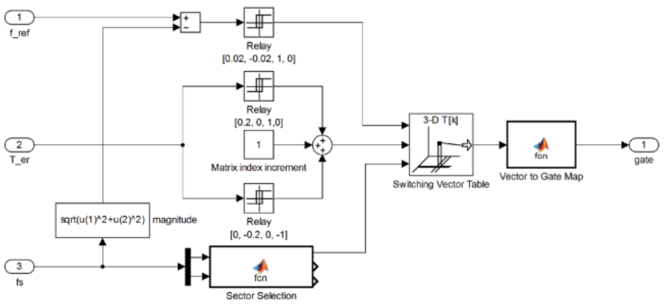

Fig. 4. DTC Controller

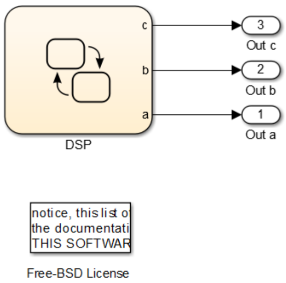

Fig. 5. DSP Block

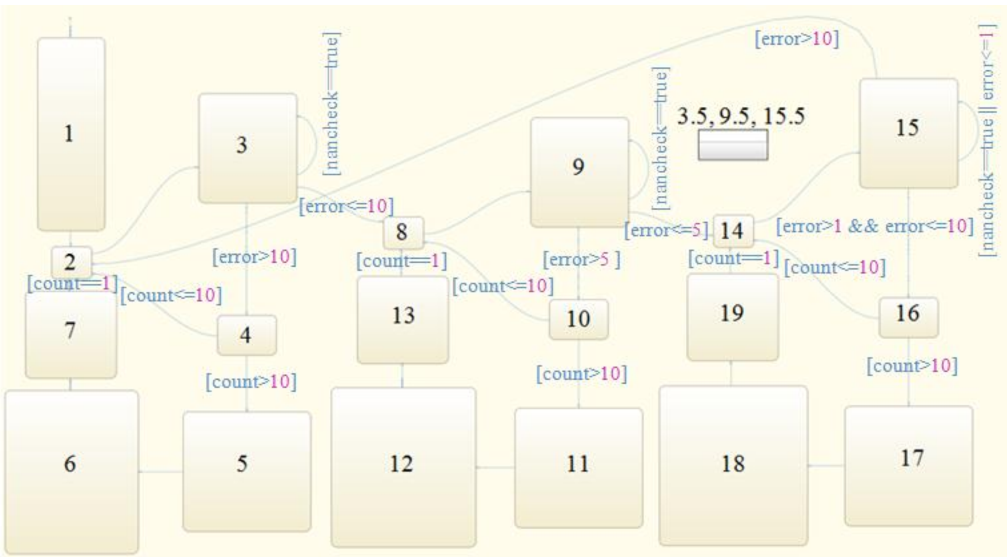

Fig. 6. Genetic Algorithm

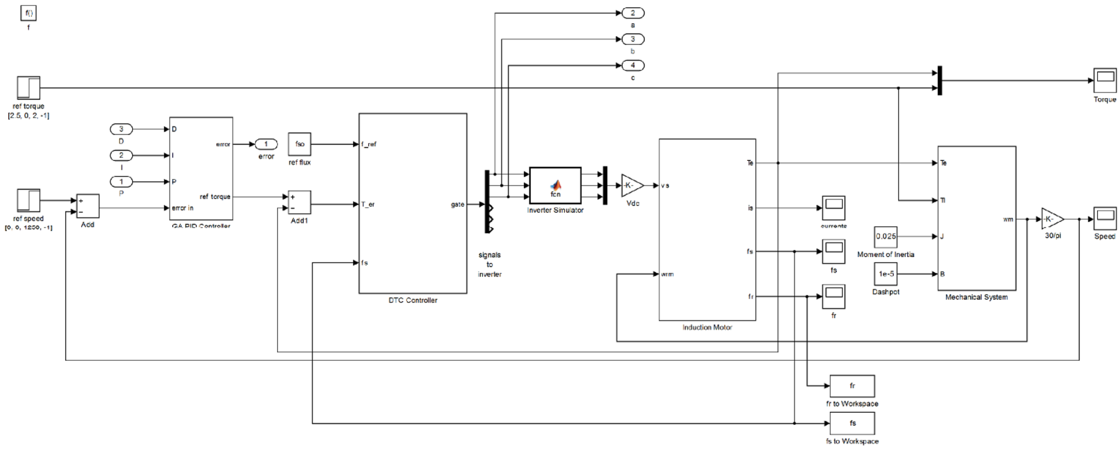

Fig. 7. Direct Torque Control of Induction Motor

V. SIMULATION RESULT

The Fig. 8 to Fig. 14 shows relevant graphs of genetic algorithm based PID tuning for DTC controlled induction motor at stator resistance, Rs = 1.77 ohm.

Initially all PID gain values are 0. It is clear from the Fig. 8 that, the proportional gain is tuned throughout the simulation until the error in speed was less than or equal to 10 rpm at around 0.5s. During that time the integral gain was tuned. When the error in speed became less than or equal to 5 rpm, derivative gain tuning was commenced. But, the oscillations in the speed response resulted in rise of error. So the derivative gain value was locked at its previous tuned value. When the error still rose, the integral gain value was also locked at its previous tuned value and proportional gain tuning commenced once again. It was observed that the convergence time for genetic algorithm for tuning such a non linear system is high.

The Fig. 13 shows the absolute error in speed. The graph reduces to zero rapidly until around 0.5s, after which error gradually rises and then falls. The current drawn is high corresponding to the initial surge in torque but at 0.5 s it settles down below to plus or minus 3.5 A.

TABLE I. PARAMETER VARIATIONS

Stator Resistance Rs (ohm)	**Values at the end of simulation**			
	Proportional Gain	***Integral Gain***	***Derivative Gain***	***Error (rpm)***
1.77	44	4.09	23.0015	56.7033
2.77	12.24	2.304	9.27	27.3849
3.77	14	39.08	25	6.2549
4.77	18	9.48	45.005	42.5336
5.77	19.07	44.08	54	16.6359

The PID gain values and the corresponding error in speed are given in Table 1. The influence of 2 Nm torque from 2.5 s on speed response is little under stator resistance of 1.77 ohm.

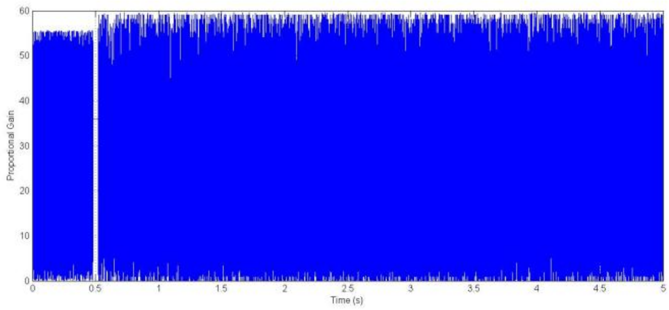

Fig. 8. Proportional Gain

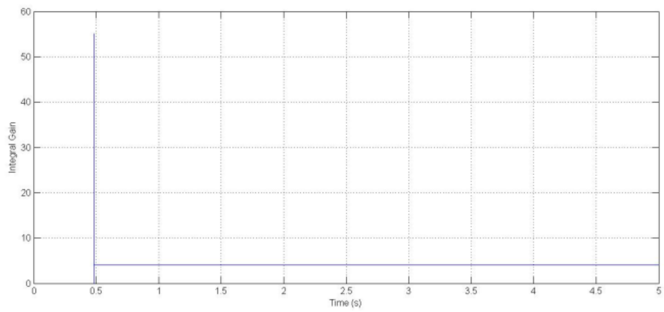

Fig. 9. Integral Gain

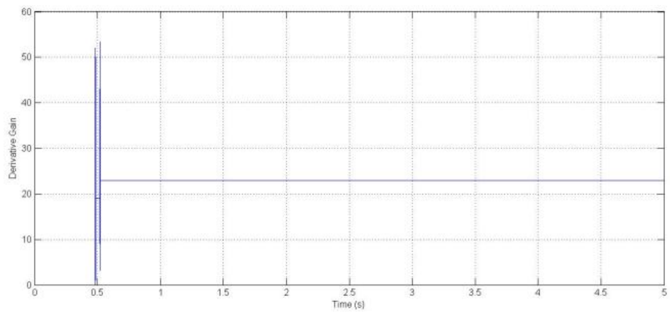

Fig. 10. Derivative Gain

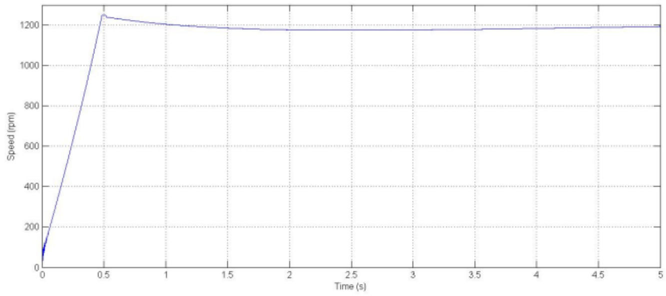

Fig. 11. Speed response of DTC controlled induction motor with PID gain values tuned from Genetic Algorithm

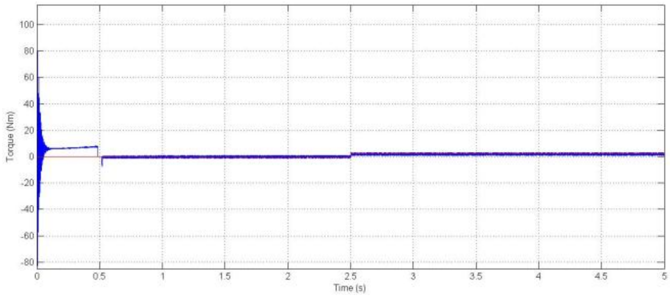

Fig. 12. Torque response of DTC controlled induction motor with PID gain values tuned from Genetic Algorithm

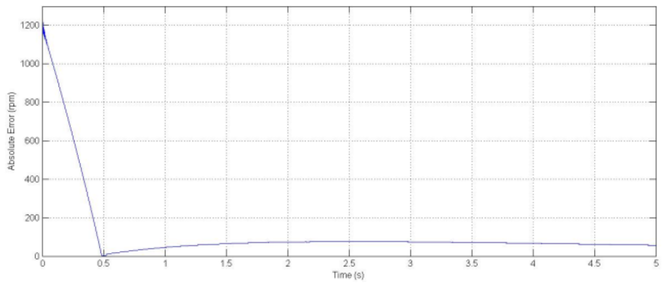

Fig. 13. Absolute Error in speed of DTC controlled induction motor with PID gain values tuned from Genetic Algorithm

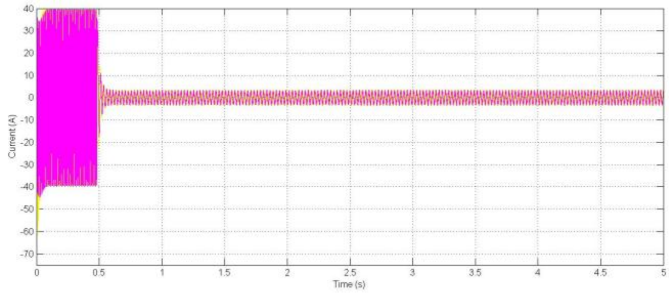

Fig. 14. Current response of DTC controlled induction motor with PID gain values tuned from Genetic Algorithm

VI. CONCLUSION

In this paper, a three phase squirrel cage induction motor was controlled using genetic algorithm based PID tuned DTC control and its performance was analyzed.

The performance of Genetic Algorithm based PID tuning for a DTC controlled induction motor was evaluated through simulation. Kp, Ki, Kd values are dynamically tuned. Parameters inside genetic algorithm need to be carefully selected to improve the convergence of Kp, Ki, Kd values.

Induction motors with DTC have an inherent obstacle which is torque ripples. The main advantage of using GA is dynamic tuning of PID gain values for making the machine operate under best operating point every time.

VII. SPECIFICATIONS OF THE INDUCTION MOTOR USED

Stator Resistance (Rs) = 1.77 ohm
Rotor Resistance (Rr) = 1.34 ohm
Stator Leakage Inductance (Lsl) = 13.93e-3 H
Rotor Leakage Inductance (Lrl) = 12.12e-3 H
Mutual Inductance (Lm) = 369e-3 H
Stator Inductance (Ls) = (Lm+Lsl) H
Rotor Inductance (Lr) = (Lm+Lrl) H
Moment of Inertia (J) = 0.025 Ns^2
Frictional Coefficient (B) = 1e-5 Ns
Number of Poles (p) = 4
Number of Phases = 3
Type = Squirrel Cage
Stator Connection = Yn
Rated speed = 1500 rpm

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APPENDIX 1

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