Neuro-Genetic Adaptive Optimal Controller for DC Motor

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Article Info	ABSTRACT
	Conventional speed controllers of DC motors suffer from being not adaptive; this is because of the nonlinearity in the motor model due to saturation. Structure of DC motor speed controller should vary according to its operating conditions, so that the transient performance is acceptable. In this paper an adaptive and optimal Neuro-Genetic controller is used to control a DC motor speed. GA will be used first to obtain the optimal controller parameter for each load torque and motor reference speed. The data obtained from GA is used to train a neural network; the inputs for the neural network are the load torque and the motor reference speed and the outputs are the controller parameters. This neural network is used on line to adapt the controller parameters according to operating conditions. This controller is tested with a sudden change in the operating conditions and could adapt itself for the conditions and gave an optimal transient performance.

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1.   INTRODUCTION

DC motors have a very good control ability and are used long time ago as adjustable speed drives, for example they are used in traction and electric cars [1], the control of these motors mainly depends on controlling the converter circuits that fed the field or the armature windings [2], [3]. Conventional controllers can be designed optimally at certain operating condition, but its performance will not be optimal for another operating point. In [4], a PID controller is designed and tuned by traditional method at certain operating point, the performance will not be the same at a different point.

Accurate model for the DC motor is essential when designing the speed controller to mimic the actual motor performance. Designing ordinary controllers depends on some simplifications such as model linearization and neglecting iron saturation. Artificial intelligence based techniques are used to design speed controller for the DC motor [5]-[12], also optimization techniques such as genetic algorithm are used to optimize the transient performance [12], [13]. Methods used either depend on the linearized model of the motor or the controller lack the adaptive property. In [14], [15] sliding mode controller is designed to control the motor speed, but sliding mode controller is suffering from the chattering phenomenon. In this paper a SIMULINK model for the DC motor is developed that consider the motor saturation and the variation of the magnetizing characteristics with the speed.

A PID speed controller is used with the armature winding, the parameter of the PID controller is optimized by genetic algorithm (GA) for each reference speed and load torque to get the best transient and steady state performance, the objective for the GA is to minimize the sum of square errors in speed taking into consideration the limits on the armature voltage. The operating conditions are varied for a wide range of reference speeds and load torques, for each point GA gets the controller parameters which are the required gains for the PID controller. Data obtained from GA are used to train a neural network, this network is simulated in SIMULINK, the function of it is to make the controller adaptive according to operating

conditions. The system is tested at different conditions and the speed controller is found to be optimized and adaptive according to each operating point.

2.   MOTOR MODELING
The mathematical model of DC motor can be expressed by the equations:

$$V_f = i_f R_f + L_f \frac{di_f}{dt} \tag{1}$$

$$V_a = i_a R_a + L_a \frac{di_a}{dt} + K_V \omega_m \tag{2}$$

$$T_e = J \frac{d\omega_m}{dt} + B\omega_m + T_L \tag{3}$$

Where:
R_f : Field winding resistance =111Ω
L_f : Field winding inductance = 10 H
R_a : Armature winding resistance = 0.24Ω
L_a : Armature winding inductance = 18 mH
K_V : Voltage constant and can be obtained from magnetization curve
T_e : Electromagnetic motor torque
ω_m : Rotor Speed in rad/sec
J : Moment of inertia = 0.5 kg.m2
B : Rotor Friction = 0.001 kg.m2/sec
V_f : Field winding voltage
V_a : Armature terminal voltage

The block diagram of speed control of DC motor using conventional PID controller is shown in Figure 1.
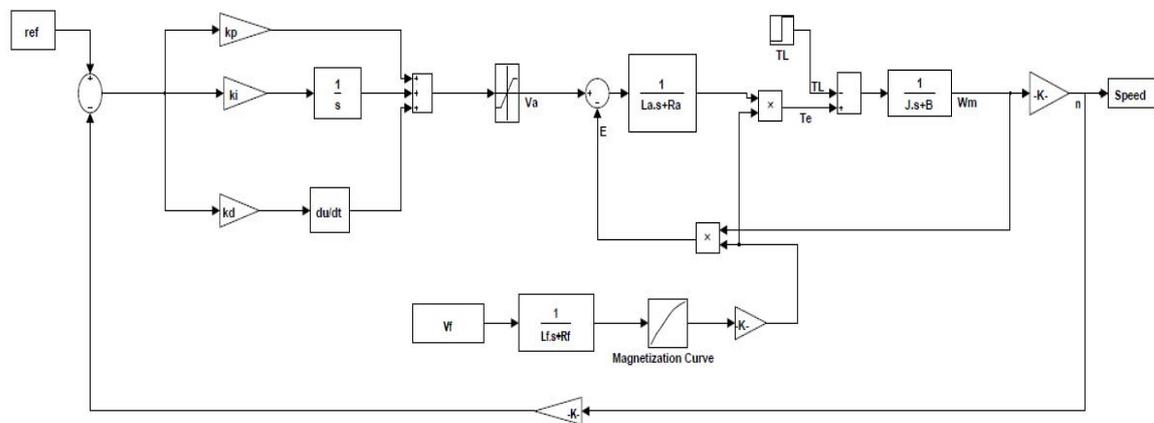

Figure 1. Block diagram of DC motor

3.   PROPOSED NEURO-GENETIC ADAPTIVE OPTIMAL CONTROLLER
GA will be used to obtain the optimum controller parameters for each operating point i.e., for any load torque and speed. The objective function of GA is to minimize the sum of square error in the transient response of the motor speed, the outputs of GA are K_p, K_d and K_i. Figure 2 shows the flow chart that describes the process of this GA. For each generation, the SIMULINK model is run and GA searches for the optimum PID controller parameters. Figure 3 shows the objective function variation with each generation for a reference speed of 1000 r.p.m and a load torque of 100 N-m.

GA is run for a wide range of motor speed (form 500 to 1000 rpm) and load torque (from 0 to 100 N-m) and a training data is obtained that used to train a neural network. The role of the neural network is to adapt the controller parameters according to the operating conditions as shown in Figure 4.
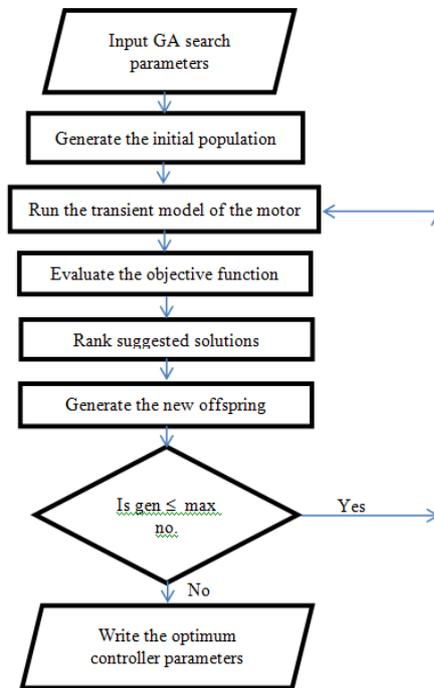

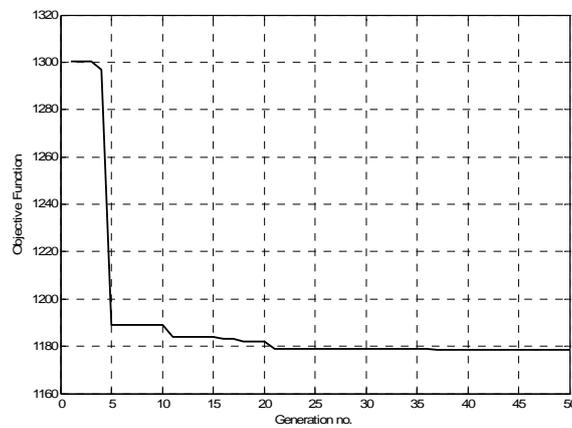Figure 2. Flow chart of GA used to obtain optimum controller parameters

Figure 3. Variation of the objective function with generations for a reference speed of 1000 rpm and a load torque of 100 N-m
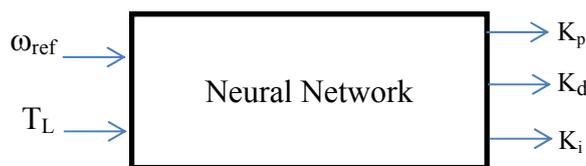

Figure 4. Function of the neural network

The neural network is a feed forward network with back propagation learning role and consists of two hidden layers of tan sigmoid activation function and an output layer of linear activation function. The numbers of hidden neurons are 21 and 2 respectively. The neural network is used on line to generate the appropriate controller parameters according to loading conditions of the motor, Figure 5 shows the block diagram of the system with the neural network.
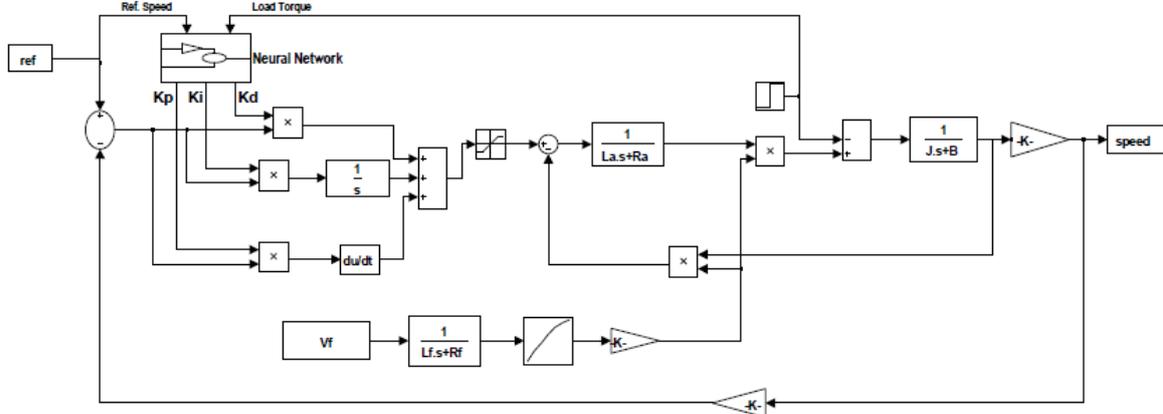

Figure 5. Block diagram of DC motor with proposed technique

4. RESULTS AND DISCUSSION

Figure 6-8 show the variation obtained by GA for the controller parameters K_P, K_I and K_D respectively with motor reference speed and load torque. It is noted that controller parameters have a wide variation with operating conditions, for example at 800 rpm the value of K_p is 350 at no load, 80 at 20 N-m and 260 at 40 N-m. The largest variation in K_i is for 500 rpm reference speed. A wide variation in K_d is with 500, 600 and 700rpm.
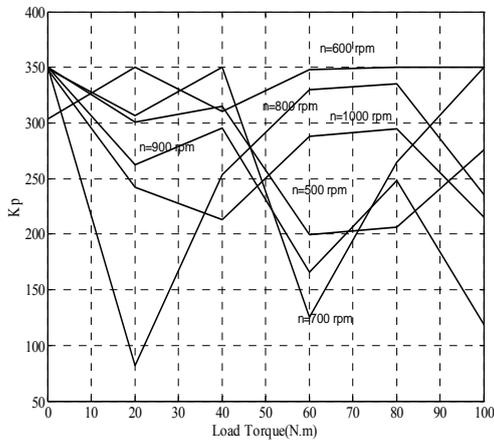

Figure 6. Variation of optimum values of K_p with load torque at different speeds
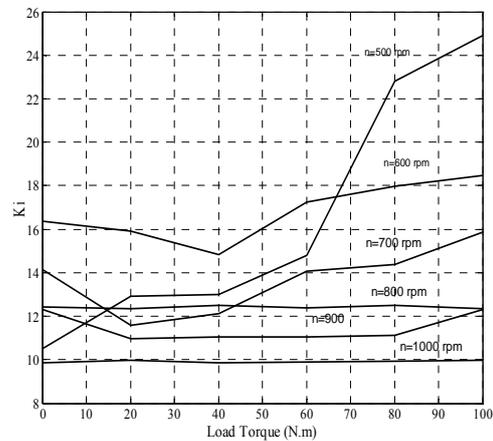

Figure 7. Variation of optimum values of K_i with load torque at different speeds
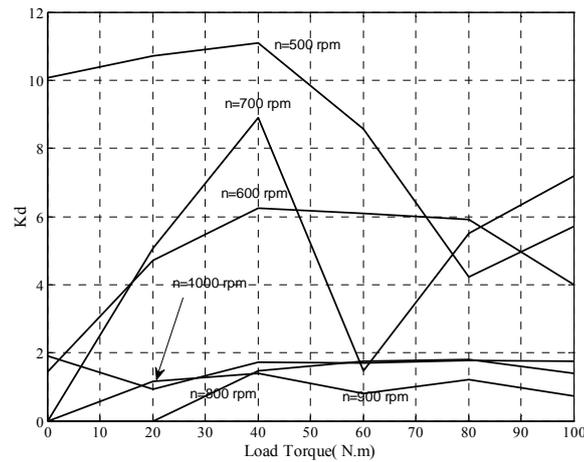
Figure 8. Variation of optimum values of K_d with load torque at different speeds

Figure 9 shows the variation of the sum square error with the number of epochs obtained while training the proposed neural network, the error goal is 10^{-8}.
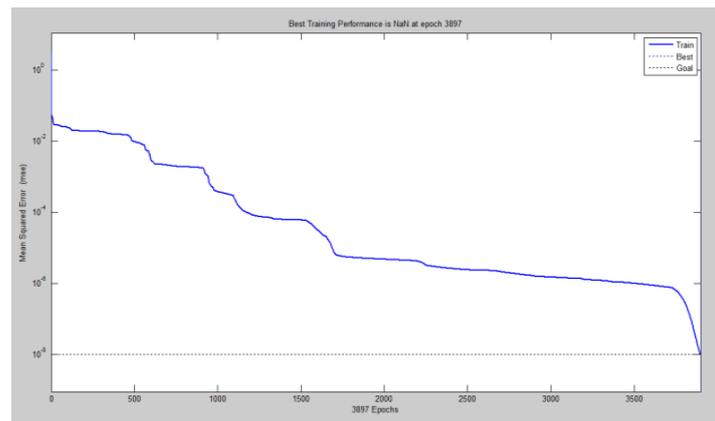

Figure 9. Variation of mean square error of neural network

To test the effectiveness of the controller, it is used with the motor model as shown in Figure 5, and motor response with this controller is compared to the response with conventional PID controller. Figure 10 shows transient response of motor speed with a reference speed command of 600, 800 and 1000 rpm and a load torque of 100 N-m. The response with the proposed controller is better than that with conventional controller in all cases, overshoot, settling time and rise time are greatly enhanced.

One purpose of the controller is to be adaptive, so that the controller structure changes with the motor operating point and became optimal for the new operating point. Figure 11 shows the response of the motor with the proposed and conventional controllers when a step change from 1000 rpm to 500 rpm is occurred at 100 N-m load. It is noticed that the proposed controller changed the controller parameters for the new speed and motor speed followed the change in reference speed command in minimum time and error, while motor speed with conventional controller is slower and has overshoot.
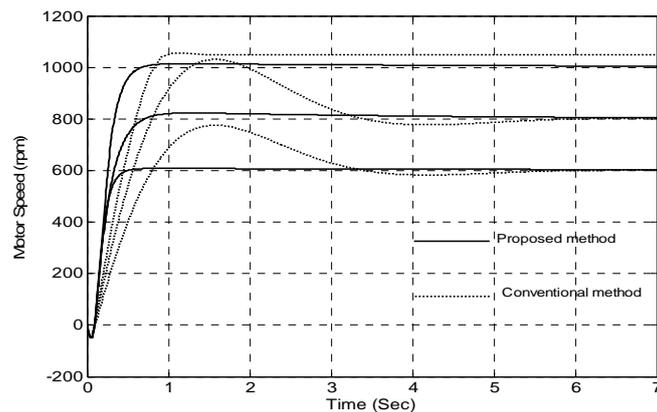
Figure 10. Variation of motor speed with conventional Controller and Neuro Genetic controller
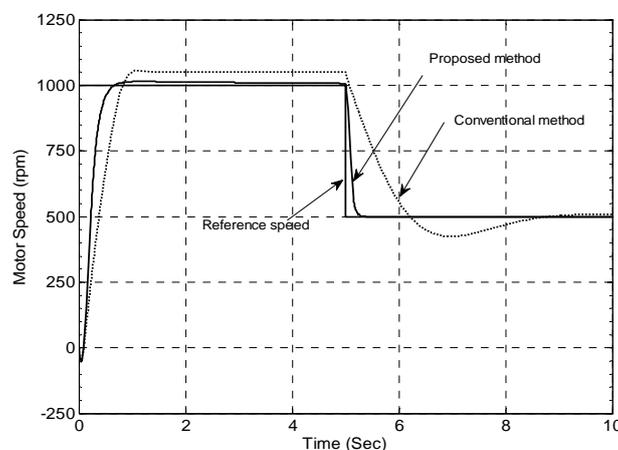

Figure 11. Variation of motor speed with conventional Controller and Proposed controller with step change in speed

5. CONCLUSION

In this paper an optimal-adaptive controller for a DC motor is designed, the controller changes its parameters according to motor operating conditions, namely motor reference speed and load torque. The proposed controller depends on GA to insure that it is optimal and a neural network to insure that it is adaptive. Motor transient and steady state response with the proposed controller has a superior performance than conventional controller.

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Mahmoud M. Elkholy received Bachelor of Engineering (B.E) degree (with honors) from Zagazig University, Egypt in 1994 under the specialization of Electrical Machines and Power Engineering, Master of Science degree from Zagazig University, Egypt 1998 under the specialization of Electrical Machines and Doctor of Philosophy (Ph.d) in the year 2001 from Zagazig University, Egypt in the Dept. of Electrical power and Machines Engineering. He has 18 years of experience in academia and research at different positions. Currently he is an Assistant Professor, College of Engineering, King Khalid University, Abha, KSA and Faculty of Engineering, Zagazig University, Egypt. His interest includes control the steady state and dynamic performance of electrical machines and artifitial intelligence.

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