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Speed Control of Brushless DC Motor Drives Based on Cuckoo Search Optimization Technique

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Abstract – Permanent magnet brushless DC (PMBLDC) motors find wide applications in industries due to their high power density and ease of control. To achieve desired level of performance the motor requires suitable speed controllers. Speed control is achieved by using conventional PI controller, PID controller and intelligent techniques such as Fuzzy controller and Adaptive Neuro Fuzzy Inference System (ANFIS). This project presents an optimized speed control technique for speed control of a BLDC motor drive system. Cuckoo search optimization technique is implemented and used to tune the PI gains of the controller. For the purpose of comparison, various other conventional and intelligent techniques are considered. From the simulation results, it is inferred that Cuckoo search offers an improvement in the quality of the speed response, reduced undershoot and overshoot problems and set point tracking performances as compared to other techniques.

Index Terms – Brushless DC motor, Sensorless system, speed control, fuzzy logic technique, Adaptive Neuro Fuzzy Inference System, Cuckoo search optimization technique.

1. INTRODUCTION

Brushless DC (BLDC) motors are preferred as small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. However, the problems are encountered in these motor for variable speed operation over last decades continuing technology development in power semiconductors, microprocessors, adjustable speed drivers control schemes and permanent-magnet brushless electric motor production have been combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications. These classic motors typically are operated at constant-speed directly from main AC power without regarding the efficiency. Consumers now demand for lower energy costs, better performance, reduced acoustic noise, and more convenience features. Those traditional technologies cannot provide the solutions.

2. MODELLING OF BRUSHLESS DC MOTOR

An important step in the design of controllers for control system is to obtain the exact mathematical model of the system which can produce output responses similar to those produced by actual system. Therefore in order to produce responses similar to those of actual system. The schematic of the electromechanical system consisting of brushless DC motor, driver circuit, inverter and mechanical load is shown below.

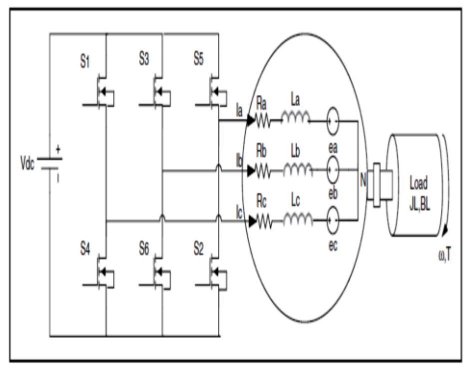

Figure .1 Schematic diagram of electromechanical system

In order to simplify the model, all the stator phase windings are assumed to have equal resistance per phase and constant self and mutual inductances, iron loss is negligible, motor flux is unsaturated and power semiconductor devices are ideal. Also it is assumed that at any instant only two phase windings conduct current. The following linear equations describing the system behavior can be represented as,

$$V_a = R_a I_a + L_a \frac{di_a}{dt} + e_a$$

$$V_b = R_b I_b + L_b \frac{di_b}{dt} + e_b$$

$$V_c = R_c I_c + L_c \frac{di_c}{dt} + e_c$$

The phase currents, phase voltages and phase back-emf are assumed to be equal. The total resistance opposing the phase current will be twice the resistance per phase

$$I = i_a = i_b = i_c$$

$$V = v_a = v_b = v_c$$

$$e_B = e_a = e_b = e_c$$

$$R = 2R_a = 2R_b = 2R_c$$

$$L = 2L_a = 2L_b = 2L_c$$

Since the torque developed by the motor is proportional to the current, the torque equation can be expressed as,

$$T_M = K_T I$$

Since the sum of all the opposing torques due to mechanical elements of motor and load torque is equal to the torque developed by the motor, the torque equation can be written as,

$$T_M = T_L + J_M \frac{dw}{dt} + B_M w$$

$$e_B = K_B w$$

$$K_b = K_T$$

The torque equation in terms of phase back-emfs and phase currents is given by,

$$T = \frac{e_a i_a + e_b i_b + e_c i_c}{w}$$

The following transfer function represents the relationship between input and output of the various blocks in the following block diagram

$$\frac{E_B(s)}{w(s)} = K_b$$

$$\frac{I(s)}{E(s) - E_B(s)} = \frac{1}{L + R_s}$$

$$\frac{T_M(s)}{I(s)} = K_T$$

$$\frac{w(s)}{T_L(s) - T_M(s)} = \frac{1}{J_M(s) + B_M}$$

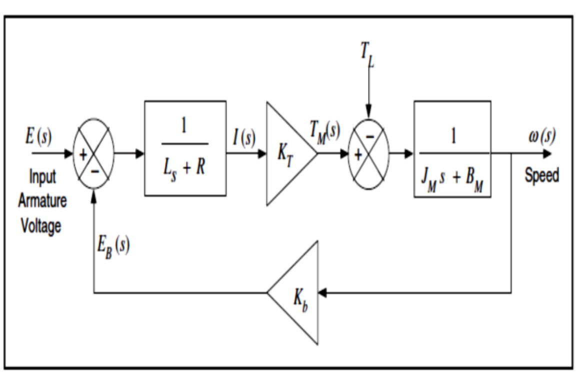

Figure.2 Block diagram of brushless direct current motor drive system.

3. CONTROLLERS USED

3.1. PI speed controller design

The PI controller calculation involves two separate modes the proportional mode, integral mode. The proportional mode determine the reaction to the current error, integral mode determines the reaction based recent error. PI controller algorithm can be implemented as

$$u(t) = MV(t) = K_P e(t) + K_I \int_0^t e\,(\tau) d\tau$$

The gain parameters of PID controller are K_I=0.22$K_P = 2.33$

3.2. PID Controller

A proportional–integral–derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. These values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. PID controller algorithm can be implemented as

$$u(t) = MV(t) = K_P e(t) + K_I \int_0^t e\,(\tau) d\tau + K_d \frac{de(t)}{dt}$$

The gain parameters of PID controller are determined using the modified Ziegler Nichols Tuning method and found to be $K_P = 0.2051, K_I = 1/0.0020, K_d = 0.0026$

3.3. Cuckoo search (CS)

Cuckoo Search (CS) is optimize the controller gains of a Proportional-Integral (PI) controller for set point tracking in speed control of a DC motor by minimizing Integral Time Absolute Error (ITAE). Hardware validation of the efficiency of above mentioned optimization algorithms is studied and presented. Cuckoo Search (CS) method does not require repeated evaluation of fitness function and can provide a set of optimal solutions within a reasonable time. CS algorithm to the problem of design space exploration and discusses their empirical comparison. And large size problems. It could efficiently deal with the problem of convergence on local sub-optimal solutions. The CS-based theoretical function of the PI controller is expressed below where Kp is the proportional gain, Ki, is the integral gain respectively. J is minimized to find the optimum PI controller's parameters, i.e., Kp and Ki giving satisfactory responses.

$$u(t)\big|_{CS} = MV(t) = K_P e(t) + K_I \int_0^t e\,(\tau) d\tau$$

The gain parameters of PI controller are determined using Cuckoo Search Tuning method and found to be $K_P = 0.1061, K_I = 1/0.002$

3.4. Fuzzy Logic controller

One of the reasons for the popularity of Fuzzy Logic Controllers is its logical resemblance to a human operator. It operates on the foundations of a knowledge base which in turn rely upon the various if then rules, similar to a human operator. Unlike other control strategies, this is simpler as there is no complex mathematical knowledge required.

E	**CE**	**NE**	**ZE**	**PE**
NCE		**NV**	**NV**	**PV**
ZCE		**NV**	**NC**	**PV**
PCE		**NV**	**PV**	**PV**

Table 1 Rules for fuzzy logic controller

The gain parameters of PI controller are determined using Fuzzy Logic Controllers Tuning method and found to be $K_P = 0.2161, K_I = 1/0.0013$

3.5. ANFIS Controller

Adaptive Network based Fuzzy Inference System neuro-fuzzy technique called Adaptive network based fuzzy inference system (ANFIS) is used as a prime tool in the present work. Adaptive network based fuzzy inference system (ANFIS) is a neuro fuzzy technique where the fusion is made between the neural network and the fuzzy inference system. In ANFIS the parameters can be estimated in such a way that both the Surgeon and Tsukamoto fuzzy models are represented by the ANFIS architecture. Again with minor constraints the ANFIS model resembles the Radial basis function network (RBFN) functionally. The gain parameters of PI controller are determined using Adaptive Network based Fuzzy Inference System Tuning method and found to be $K_P = 0.2061, K_I = 1/0.0012$.

Definition	Data/unit
Rated voltage	36V
Rated current	5A
No. of poles	4
No. of phases	3
Rated speed	4000RPM
Rated torque	0.42Nm
Torque constant	0.082 N.m/A
Mass	1.25 kg
Inertia	23 e-06 kg-m2
Resistance per phase	0.57_
Inductance per phase	1.5Mh

Table 2 Specifications of BLDC Motor

4. SIMULATION RESULTS

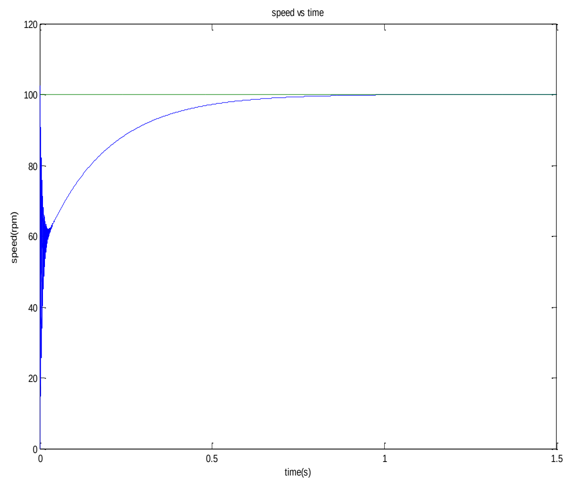

Figure 3. Output waveform of pi control

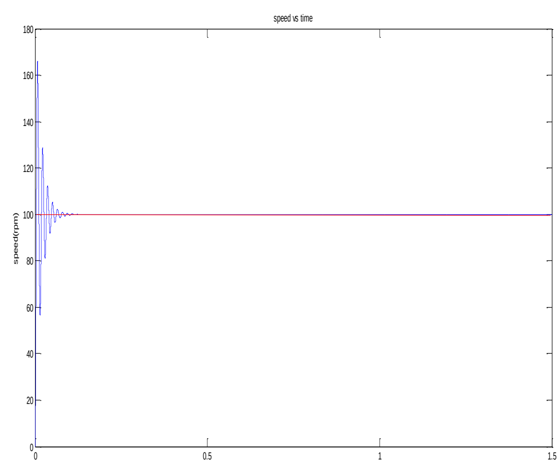

Figure 4 Output waveform of pid control

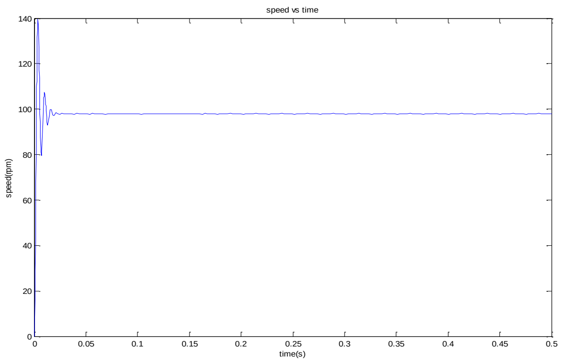

Figure 5 Output waveform of Fuzzy control

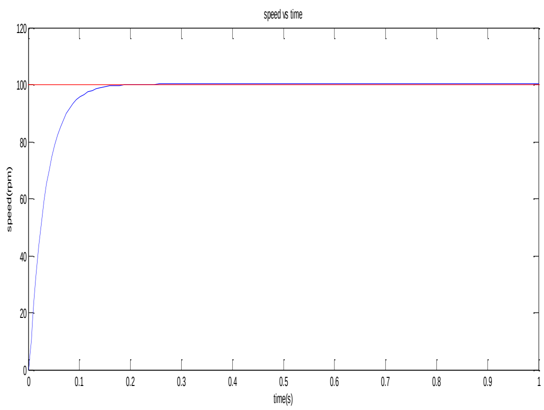

Figure 6. Output waveform of ANFIS control

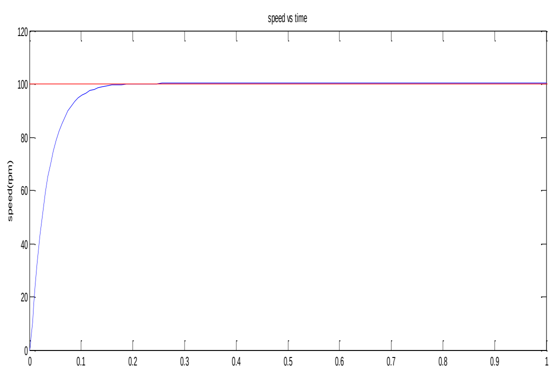

Figure 7 Output waveform of Cuckoo search technique

5. CONCLUSION

In this project speed control is achieved by using Proportional-Integral (PI) controller, Proportional Integral and Derivative (PID) controller, Fuzzy controller and ANFIS controller. These controllers pose difficulties where there are some control complexity such as nonlinearity, load disturbances and parametric variations. It is found that Cuckoo Search optimization technique control offers an improvement in the quality of the speed response, reduced undershoot and overshoot problems compared to other convention control.

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