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FUZZY LOGIC PID SPEED CONTROLLER FOR BRUSHLESS DC MOTOR DRIVES

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Abstract:
A simple but robust fuzzy speed controller for the brushless dc motor drives is proposed. The output is adjusted by fuzzy rules according to the current value of the speed error and the associated rate of change. Using only five triangular membership functions with twenty-five rule-base inference engine, the implementation of the controller was made possible. The proposed controller mixes two control actions, the fuzzy logic controller as proportional derivative control action and a non-fuzzy integral controller to eliminate the steady state error. The overall controller design is equivalence to proportional-integral-derivative (PID) controller. The fuzzy logic controller plays the main role and the added integral controller is just to provide a variable bias to eliminate the steady state error at every load condition. The sampling time in the designed controller is 200 μs. Which allows the use of low speed-processing device in the implementation of the control algorithm. The proposed speed controller succeeded in controlling the speed of a brushless dc motor over all operating speed range of the drive. From the response results, it is found that the controller operates like adaptive controllers but without the complication needed to do it adaptively. The performance of the proposed controller was assessed in terms of several simulation cases. The responses due to step set point change and load disturbance showed that the proposed controller is controlling the speed of the brushless dc motor drive with fast non-oscillatory behavior. The proposed controller makes the control system response similar over a wide range of operating points.

Keywords:
Fuzzy logic controller, PID self-tuning controller, Speed Control, brushless DC motor drives

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1. INTRODUCTION

The most widely used controller in industrial application is PID-controller . It is easy to tune and it has good disturbance attenuation properties. A disadvantage of PID controller is that it is linear and cannot successfully control nonlinear system. Fuzzy logic controllers have been reported to be successfully used for a number of complex and nonlinear processes [1]. In fuzzy logic control, PD-type and PI-type fuzzy logic controllers are the best-known counterparts of the PID controller. They are used to achieve better performance with nonlinear processes. A PD-Fuzzy logic controller would be suitable to control a process which exhibits unacceptable oscillations in its set point . The control action can be adjusted to give fast non-oscillatory responses at every operating point by properly designing the set of rule base of the fuzzy logic controller. However, PD controllers suffer from non-zero steady state error. On the other hand PI-fuzzy controller has adverse effect and cannot be used for law-damped process[1,2].

Fuzzy set control is often used to implement intelligent controllers. This technique is applied to uncertain systems whose models cannot be utilized to generate robust control. The fuzzy expert system can also make multistage decision as general expert makes. The majority of fuzzy logic control systems are knowledge – based systems. For these systems, their fuzzy model or their fuzzy logic controllers are described by fuzzy If-Then rules, which have to be established based on the experts' knowledge about the system , controller, performance, etc. Moreover, the introduction of input-output intervals and membership functions is subjective, depending on the designer's experience and the available information. However, we emphasize once again that after the determination of the fuzzy sets, all mathematics to follow are rigorous . so the purpose of designing and applying fuzzy logic control systems is above all, to tackle these vague , ill-described, and complex processes that can be hardly handled by classical systems theory and classical control technique, as well as the classical two-valued logic. In these fuzzy logic control systems; the fuzzy logic controller directly performs the control actions and thus completely replaces the conventional control algorithm. Yet there is another type of fuzzy logic control system; namely the fuzzy logic controller involved in a conventional control system and thus becomes part of mixed control algorithm, to enhance or improve the performance of the overall control system[1,3].

Permanent magnet motors are preferred in manufacturing electrical machines for the many benefits that it gives over the other types. Of these benefits, there are no rotor copper losses and so high efficiency, higher torque or output power per volume which results in lower weight and better dynamic performance due to higher flux density in the air gap. Because of these benefits and the improvements in the properties of permanent magnet materials in recent years, there is a wide attention for application of PM motors in industry. Specially, low power range PM motors are very good alternative to induction motors when controlled motor drive are required[4,5].

The brushless dc motor is by definition a permanent magnet synchronous motor supplied from voltage source inverter, which is switched so that the frequency of its applied stator voltage is equal to its rotor speed. Many investigators are applying the method of vector control or field orientation technology to permanent magnet synchronous motors in order to make their characteristics similar to that of dc motors[6]. This technique gives the permanent magnet synchronous motor drives more advantages of working with zero direct axis stator current component and the electrical torque is produced directly from the quadrature axis stator current. Therefore, reaching the state of maximum torque per ampere and fast dynamic response of the drive. The control of the brushless DC motor can also be modified to operate with zero stator direct current by simply controlling its voltage source inverter [5,6,7].

The interest in this paper is to design a speed controller for a field oriented brushless dc motor drive. The proposed speed controller is a hybrid type mixing both the advantage of a fuzzy logic controller working as proportional derivative type, with the digital integral controller. Thus obtaining the total control effect of the PID controllers. The overall system was designed and simulated by using the Simulink facilities in the Matlab program together with the fuzzy logic toolbox. A series of tests were performed with the aim of evaluating the behavior of the speed controlled field oriented brushless dc motor drive for different transients at different speed set points. The transients encompassed by the present study include response to a large step speed command from standstill with nominal inertia and with an increased inertia. Response to small step speed reference change with nominal inertia and with an increased inertia, as well as response to step load torque application. The speed response is examined for at least three speed settings for each transient, so that an insight into the impact of the operating point on the controller behavior is enabled.

2. MODELING OF THE PROPOSED SPEED CONTROLLER

The simulated system under consideration is shown in Fig.1. The speed controller inputs are the speed error signal and its rate of change , both signals were sampled at 200 μs as sampling time. The speed controller composed of two parallel branches. The first one is the fuzzy logic controller and the second is the integral controller. The outputs of the two controllers are summed up and used to manipulate the input to the voltage source inverter. The data for the brushless dc motor used is shown in appendix.

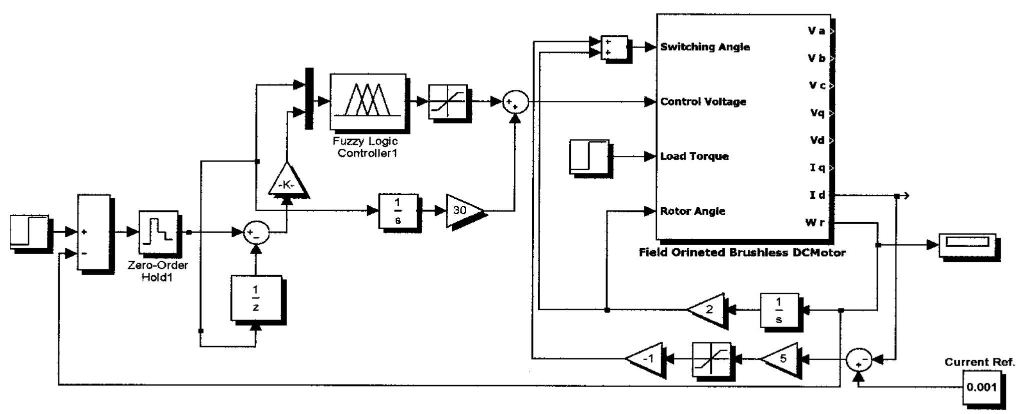

Fig. 1 The block diagram of the overall system

A)The speed Controller

The speed controller is developed and tuned using SIMULINK-MTLAB and Fuzzy logic toolbox. The controller has two inputs and one output and consists of two controllers operating in parallel. One of the controllers is a fuzzy logic controller and the other is the conventional integral controller.

1)The fuzzy logic controller

The general structure of a fuzzy logic controller (FLC), consists of three basic portions: the fuzzification unit at the input terminal, the inference engine built as the fuzzy logic control rule-base in the core and the defuzzification unit at the output terminal. The designed fuzzy logic controller in this system constitutes of five membership functions with overlap, of triangular shape and equal width as shown in Fig.2. A twenty-five rule base was created and listed in Table 1.

In the proposed control scheme the system variables, which are the input to the FLC are the speed error e(k) and its rate of change Δe. These variables are sampled from their actual values and are expressed by the following equations in digital form:

$$e(k) = \omega_{ref}(k) - \omega(k) \quad (15)$$

$$\Delta e(k) = \frac{e(k) - e(k-1)}{T_s} \quad (16)$$

Where ω_{ref} , ω , T_s and k are the reference speed , the actual speed , the sampling time and the sampling instant respectively.

2) The Integral Controller

As a fuzzy logic controller on its own is PD controller equivalent. An integral controller is used in parallel with the fuzzy logic controller. The integral controller input is the speed error signal only and its output is mixed with the output of the fuzzy logic controller.

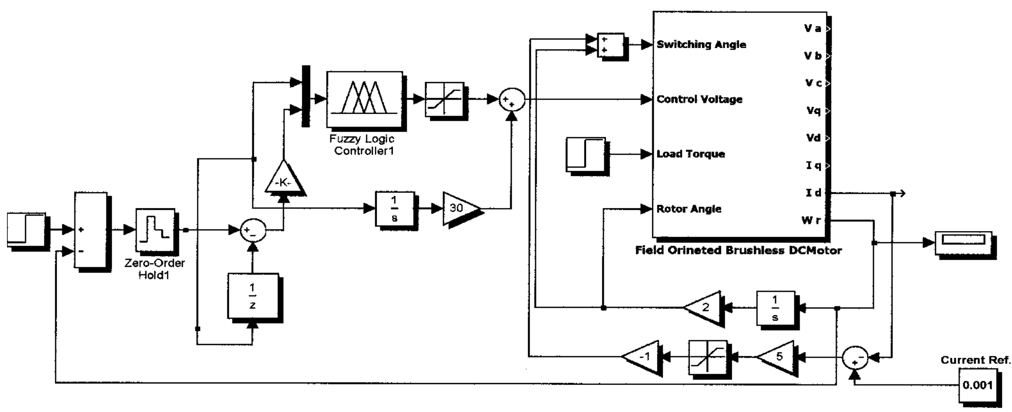

Fig. 3 The block diagram of the Brushless DC motor

A. Response to Step Speed Command from Standstill, Rated Inertia, No-Load

The drive is initially at standstill without any simulated load torque on its shaft. Figs.4a,b,c,d present the simulated speed responses for speed references equal to 180 rad/s, 100 rad/s , 50 rad/s, and 10 rad/s. The fuzzy logic speed controller provides fast and non-oscillatory speed response . The responses remain aperiodic at all speed settings, and the settling time is very small .

B. Response to Step Speed Command from Standstill, Rated Inertia, Full load Torque

The drive was initially at standstill with simulated full-load torque on its shaft. Figs.5a,b present the simulated speed responses for speed references corresponding to 180 rad/s, 50 rad/s. The fuzzy logic speed controller provides the same responses as that obtained at no-load torque condition . The responses remain aperiodic at all speed settings, and the settling time is very small .

C. Response to Step Speed Reduction of Speed Command, Rated Inertia, Full Load Torque

The drive initially operates at steady state condition supplying full-load to the connected load and then a step speed reference reduction amount of 40 rad/s at each case of the reference setting is applied. The results of this case are given in Figs.6a,b for three initial speed values, namely 180 rad/s, 100 rad/s. The response showing a very smooth landing of the speed signal to accommodate with the new steady state speed . No oscillation in the response associated with fast response of the transient.

D. *Response of Step Speed Command from Standstill, Increased Inertia*

This situation is a simulation of the practical case of increased inertia of the whole system due to the added inertia of the load to that of the motor. An effective increase in inertia is therefore achieved, of the order of 2 to 1. Figs.7a,b show the response to application of the step speed references amount to 180rad/s, and 50 rad/s. Operation in the current limit takes place for a prolonged period of time. This is the reason of the shown overshoot in the speed responses of Fig.7. The fuzzy speed controller showed a speed response which is not different from the case of rated inertia. This prove the robustness feature of the whole speed control system.

E. Response to sudden unloading of the motor

The drive is initially operated at steady state supplying the full-load torque and at a later instant of time, the load torque is suddenly released from the motor shaft. The responses with the previous steady state operation at 180 rad/s and 50 rad/s is illustrated in Fig.8a,b.

F. Load Rejection Transients

The load is applied in a step-wise manner in the steady state no load operation . Results of the load rejection transient are given in Figs.9a,b for 50 rad/s and 10 rad/s reference speed settings. The fuzzy logic speed controller offers excellent speed response, with small speed dip and short recovery time, regardless of the speed reference setting.

3. CONCLUSION

The investigation of combining a fuzzy logic controller with a conventional integral controller on the performance of the field oriented drives are presented. The performance of the drive was investigated for load rejection transient, large step speed command from stand still with rated and with double the rated inertia of the drive . The small step decrease in reference speed with rated inertia was also investigated. In contrast to the existing studies, where transient behavior is usually examined for single speed reference setting. All the simulations are performed at different reference speed settings. Examination of the impact of the reference speed setting on the speed response is thus enabled. Fuzzy logic controller makes the system response more robust to changes in parameters.

The obtained results show that Fuzzy logic speed controller provides fast and non-oscillatory speed response . The responses remain aperiodic at all speed settings and the settling time is very small . The responses show a very smooth landing of the speed signal to accommodate the new steady state speed when it is required to change from one setting to another. The transient most susceptible to the speed reference setting appear to be the response to a large step speed reference application with an increased inertia and response to a small step speed reference change with increased inertia. Load rejection capability was , unaffected by the reference speed setting to a large extent.

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APPENDIX

The parameter of the simulated drive are:
Phases: 3
Poles: 4
$L_s = 0.0795$ H
$r_s = 1.5\ \Omega$
$J = 0.003$ Kg/m^2
$B = 0.0008$ (Nm)/(rad/sec).
$\lambda_d = 0.0865$ Volt/sec.
$T_{fl} = 4$ Nm.

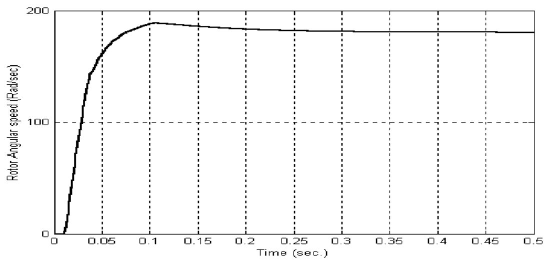

Fig.4a

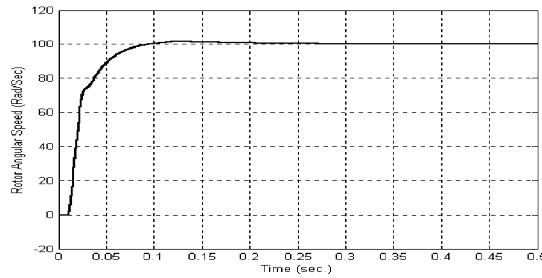

Fig.4b

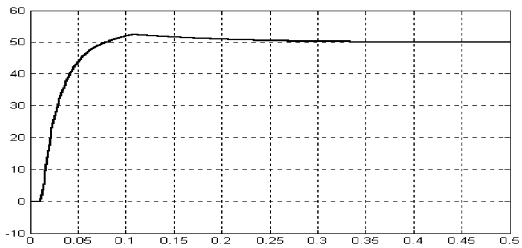

Fig.4c

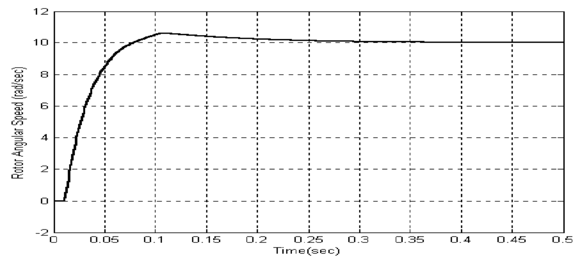

Fig.4d

Fig. 4 Responses for step increase in speed reference from standstill and at no-load torque, (a) for 180 rad/s,(b) for 100 rad/s, (c) for 50 rad/s, (d) for 10 rad/sand.

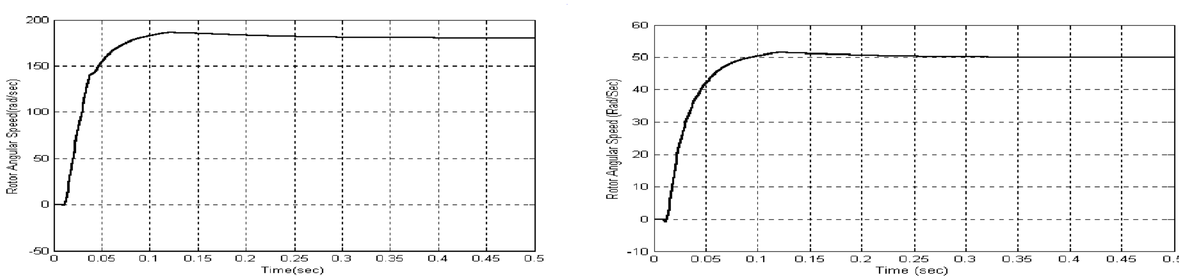

Fig. 5 Responses for step increase in speed reference from standstill with full-load torque supplied, (a)for 180rad/s (b)for 100 rad/s.

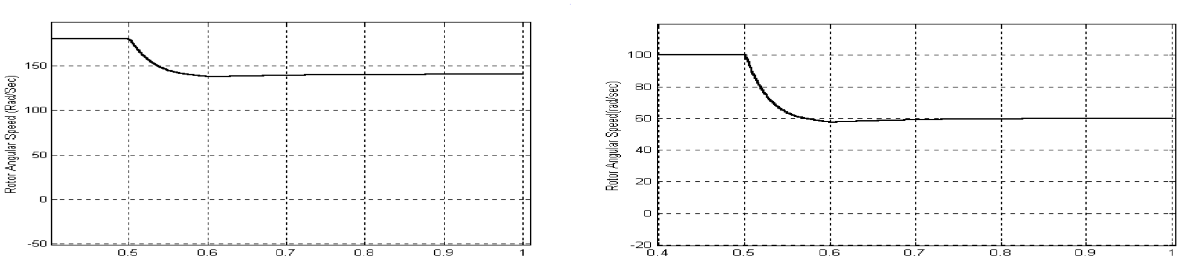

Fig6 Responses for a step decrease in speed reference amount to 40 rad/s , for initial steady state speeds of, (a) 180 rad/s ,(b) 100rad/s

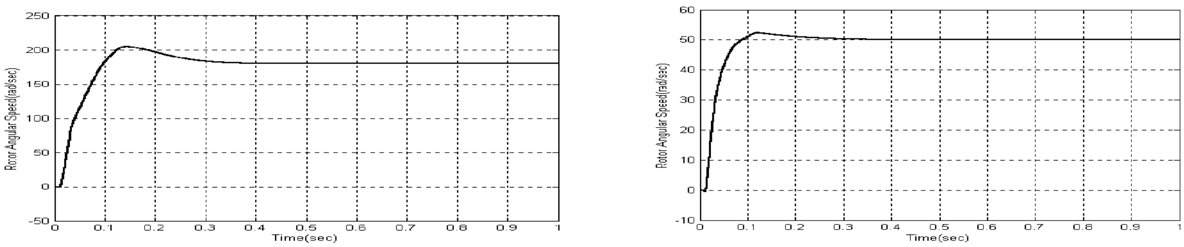

Fig. 7 responses of sudden increase in the speed reference from standstill with full-load torque supplied and for speed references of (180)rad/s, (b) 50 rad/s.

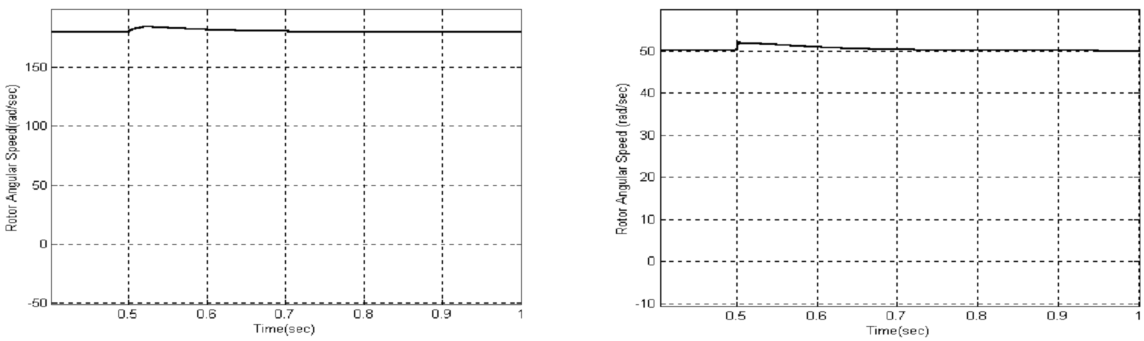

Fig.8 Responses for sudden unloading the motor from full-load to no-load torque, initial steady state speeds of ,(a) 180 rad/s, (b) 50 rad/s

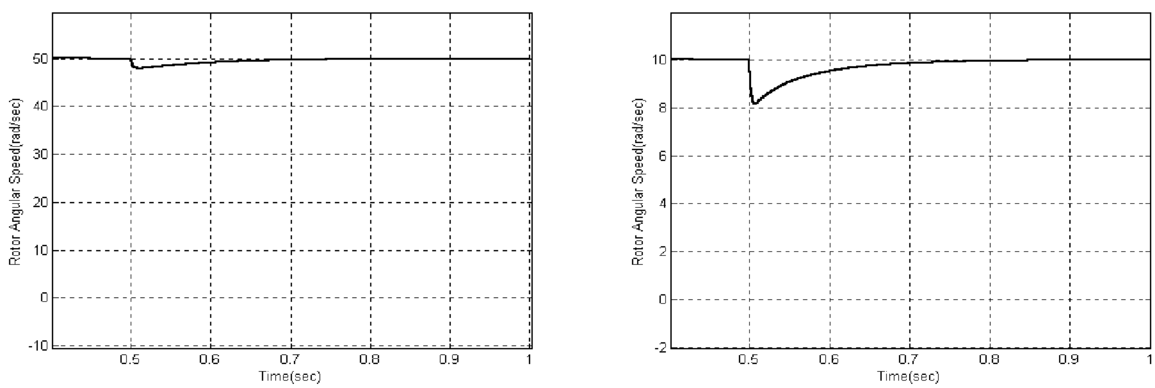

Fig. 9 Responses for sudden loading the motor from no-load to full-load torque, initial steady state speeds of ,(a) 50 rad/s, (b) 10 rad/s