Indian Journal of Science and Technology, Vol 8(35), DOI:10.17485/ijst/2015/v8i35/68960, December 2015
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Variable Sampling Effect for BLDC Motors using Fuzzy PI Controller

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Abstract

Background/Objectives: The variable sampling effect the response time taken to attain its speed of the motor is low whereas, response time is high. **Methods/Statistical Analysis:** The simulation tool includes three parts, the first is continuous time model of BLDC motors, the second is variable sampling trigger, and the next is the discrete time speed and variable sampling time constant estimator. **Findings:** Variable sampling systems describe a class of systems whose sensor outputs are obtainable only at some situations not specified by the sampling mechanism. In our proposed work, a fuzzy PI controller based on variable sampling for BLDC motor drives with low resolution position sensors (Hall sensors). It is not only easy to understand as the conventional PI controller, but also more robust in variable speed control. We use three PI controller based on different sampling time at the same time, a fuzzy logic controller to calculate command. The only input variable of our fuzzy logic is rotor speed of the BLDC motor, because the sampling time thus becomes a variable according to the motor speed and the response time is high. **Application/Improvements:** This type method used for air-conditioner, fans etc.

Keywords: Fuzzy PI Controller, Hall Sensors, Sampling Time

1. Introduction

Because of their reliabilities, high performance motion control of machine tools, flexibilities and low cost, DC motors are widely used in industrial applications where speed and position control of motor are required. Brushless DC motors have recently been widely used in industrial and household product for its advantage in size, efficiency, structure, operating life, and speed range[1,2]. Limitations of brushed DC motors overcome by BLDC motors include lower efficiency and susceptibility of the commutator assembly to mechanical wear and servicing, cost with less rugged and more complex and expense, BLDC motors offer better speed versus torque characteristics, efficiency increases, dynamic response is high, increase in operating life, operation takes without noise and higher speed ranges PID controllers are commonly used for motor control applications because of their simple structures and intuitionally comprehensible control algorithms.

The classical method of controlling the speed of BLDCMs is Proportional-Integral-Derivative (PID) control. This method is usually applied by tuning the PID parameters (K_p, K_i and K_d)[4,5]. Usually, when suffers from various conditions or sudden change of speed, the system can hardly maintain the good performance achieved under the original parameters without retuning the PID parameters. Controller parameters are generally tuned using hand-tuning or Ziegler-Nichols frequency response method. This method has good result but long time and effort are required to obtain a satisfactory system 37 response. Two main problems encountered in motor control are the time-varying nature of motor parameters under operating conditions and existence of noise in this system loop. Analysis and control of complex and time-varying systems is a challenging task using conventional

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methods because of uncertainties. Fuzzy set theory, which led to a new control method called Fuzzy Control which is able to cope with system uncertainties. The fuzzy set theory helps a lot when dealing with uncertainty. Microcontrollers have made using fuzzy logic control popular for nowadays. Fuzzy logic controllers have the advantages of working with various inputs, an accurate mathematical model is not required, and handling nonlinearity[3,6]. A certain mathematic model of the nonlinear dynamic BLDCM control system is not necessary when using a fuzzy logic controller. So, despite the varying loads and changing parameters, we can still achieve great performance by combing fuzzy logic control with classical PID controller[7,8].

In this proposed work, a robust control in multi-rate or variable sampling, their controllers were complex to implement. And, the fuzzy logic controllers are shown to be efficient tools for control of nonlinear and uncertain parameter. In this proposed fuzzy logic and conventional PI controller is a far more appropriate solution for the robust control.

2. System Architecture

Fuzzy logic techniques have a real time basis as a human type operator, which makes decision on its own. However, the fuzzy logic controller has complexity is one of the main problems about designing fuzzy logic controllers.

The complexity, which is defined as the size of the fuzzy rule base of the fuzzy controller, increases as the number of fuzzy if-then rules increases and the number of rules increases exponentially as the number of input variables of the fuzzy controller increases. In order to reduce the complexity, we present the fuzzy PI controller for BLDC motors considering variable sampling effect.

The controller, which we present, includes three dual inputs but single rule for the fuzzy logic and three PI controllers in different sampling time, as shown in Figure 2. Although there are two inputs (speed error and rotor speed) in fuzzy logic, the fuzzifying, control rule and defuzzification are based on the rotor speed (co). The major work of the fuzzy logic is scaling speed error for PI controller.

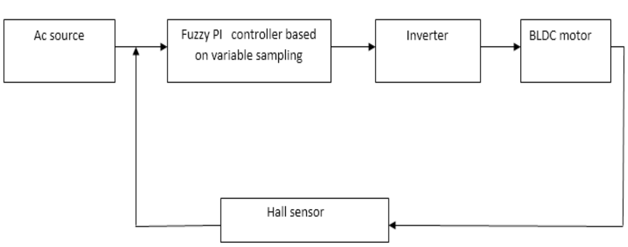

Figure 1. Proposed system.

2.1 Fuzzyifing

The three fuzzy logic are based on rotor speed (C_0), and the speed is defined on the universe of discourse 0 to 3000 rpm.

$$y_L(\omega)=\begin{cases}1, & \text{for} \quad \omega<500\\ \dfrac{1500-\omega}{1000}, & \text{for} \quad 500\le\omega\le1500\\ 0, & \text{for} \quad \omega>500\end{cases}$$

$$y_M(\omega)=\begin{cases}0, & \text{for} \quad \omega<500\\ \dfrac{\omega-500}{1000} & \text{for} \quad 500\le\omega\le1500\\ \dfrac{2500-\omega}{1000} & \text{for} \quad 1500\le\omega\le2500\\ 0, & \text{for} \quad \omega>2500\end{cases}$$

$$y_H(\omega)=\begin{cases}0, & \text{for} \quad \omega<1500\\ \dfrac{\omega-1500}{1000}, & \text{for} \quad 1500\le\omega\le2500\\ 1, & \text{for} \quad \omega>2500\end{cases}$$

The input membership functions of the fuzzy sets are trapezoidal and triangular exception. Figure 2. shows the membership distribution where the fuzzy variables are labeled with “LS”, “MS”, and “HS” to represent “low speed”, “median speed”, and “high speed”.

And, the mathematic of the membership functions are shown above. Y_L is the membership degree of the fuzzy

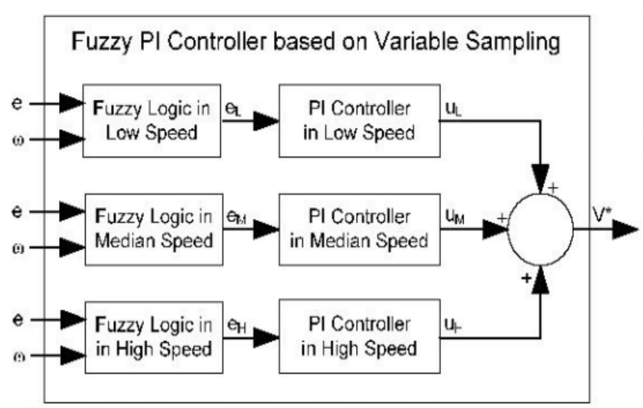

Figure 2. Fuzzy PI controller based variable sampling.

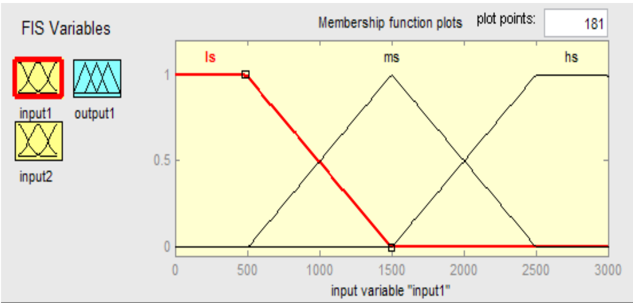

Figure 3. Fuzzy membership function for input-1.

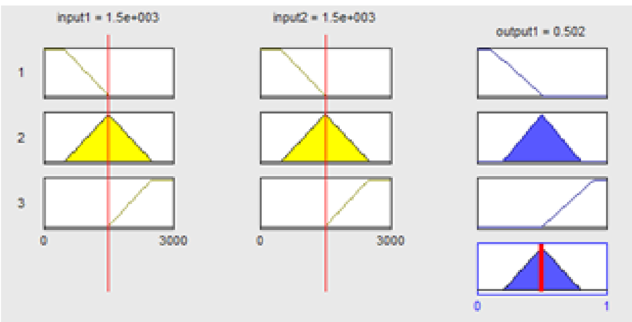

Figure 4. Fuzzy rule viewer for speed.

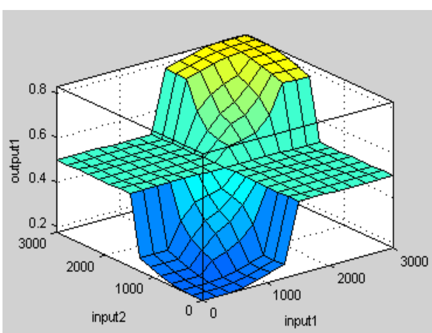

Figure 5. Surface viewer for the speed.

logic in low speed, y_m is the membership degree of the fuzzy logic in median speed, and y His the membership degree of the fuzzy logic in high speed. C_0 is the rotor speed.

2.2 Fuzzy Control Rule

The rules of the fuzzy logic can be shown as the following:

R_L:If ω is LS, then e_L is e.
R_M:If ω is MS, then e_M is e.
R_H:If ω is HS, then e_H is e.

R_L, R_M, and R_H are the control rules in different speed. e_L, e_M, and e_H are the outputs of fuzzy logic. e is the speed error. There are only three control rules, so the fuzzy PI controller for BLDC motors considering variable sampling effect, we present, can be implemented easily.

2.3 Defuzzification

To calculate the output, a multiplication is used for defuzzification.

$$e_L = e \cdot y_L$$
$$e_M = e \cdot y_M$$
$$e_H = e \cdot y_H$$

From the scaled speed error (e_L, e_M, and e_H), the three PI controllers can calculate three voltage commands (U_L, U_M, and U_H). This three fuzzy logic scale speed error for different sampling time PI controller, so it can be implemented and understand easily. Because the scaled speed error (e_L, e_M, and e_H) is based on rotor speed, the fuzzy PI controllers can achieve variable sampling in BLDC motor drives using Hall sensor.

3. Simulation results

In SIMULINK, there are continuous and the fixed sampling rate discrete modes, but there is no suitable mode for variable sampling rate of BLDC motors. A simulation method for variable sampling rate based on time domain simulation of SIMULINK is proposed, as shown in Figure 6.

The simulation tool includes three parts: the first is continuous time model of BLDC motors, the second is variable sampling trigger, and the next is the discrete time speed and variable sampling time constant estimator.

In continuous time model of the BLDC motor, we designed transfer function of BLDC motor according to

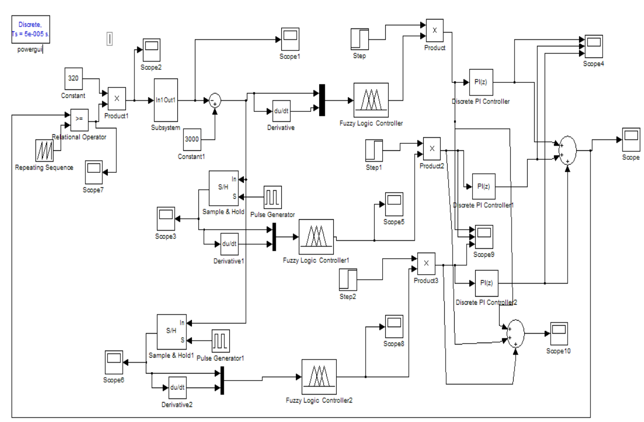

Figure 6. Simulation block diagram.

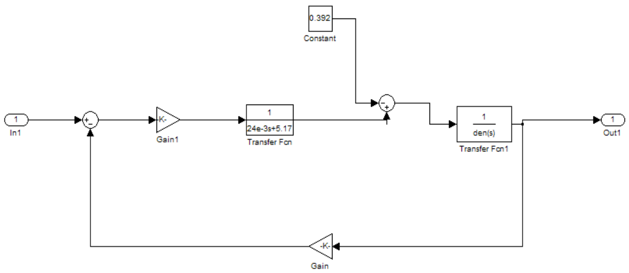

Figure 7. Transfer function for BLDC motor.

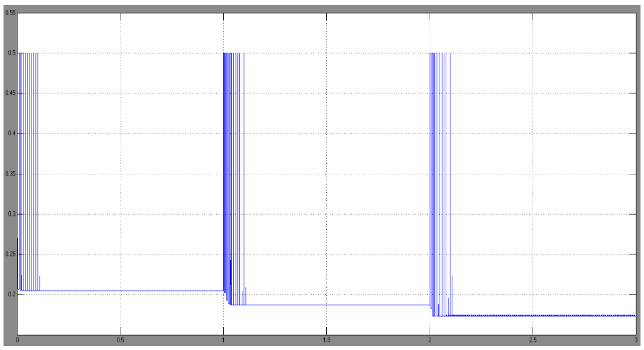

Figure 6. Speed error in BLDC motor for 0.2 sec

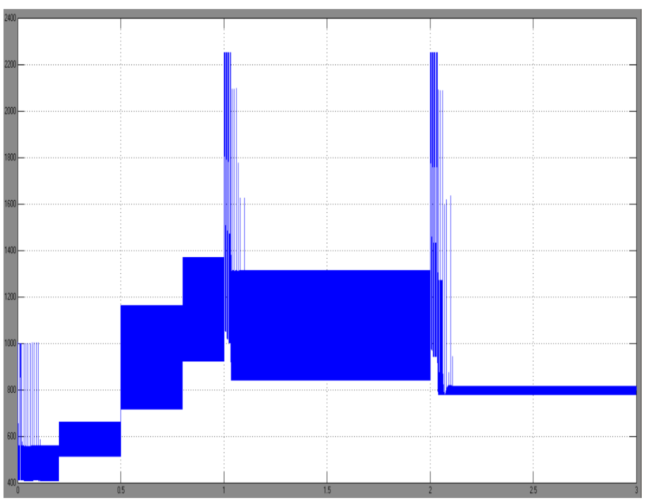

Figure 8. Speed Error in BLDC motor before using variable sampling effect.

the motor rating of the BLDC motor. In this the voltage command which is compared to the triangular wave to get the gate signal to produce waveform to inverter.

In variable sampling trigger the sampling time varies for the motor speed. In this the halleffect sensor sends the feedback signals per 2 π/12 radians. We integral rotor speed to angle π/6 which is divided by the angle of BLDC motor.

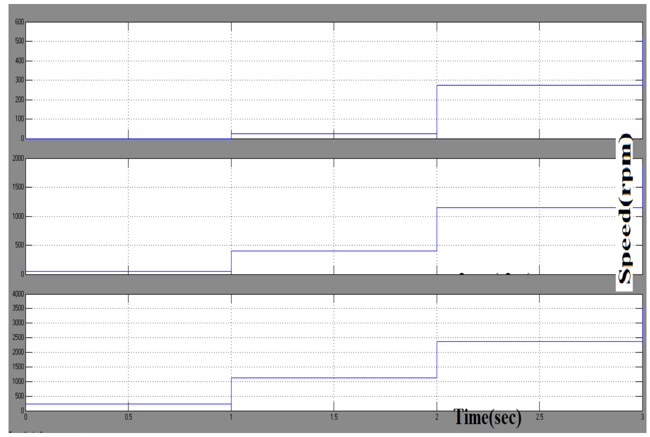

Figure 9. Experimental results of the fuzzy PI controller for BLDC motor at variable motor speed.

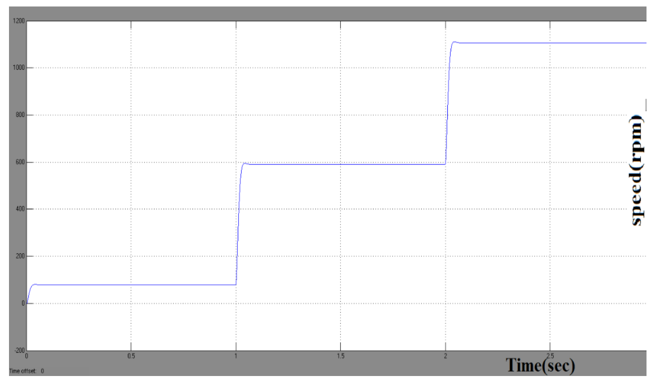

Figure 10. Experimental results of the fuzzy PI controller for BLDC motor at variable sampling effect.

By this, the trigger will give us the Discrete time speed and also the variable sampling time constant estimator. When the angle which is divided will give the reminder one or zero in SIMULINK. We have the boundary to be maintained by angle of BLDC motor which is divided by π/6.

The sampling trigger which has sample and hold block to sample speed, then the variable sampling time interval can be calculated by sampled time speed, as shown in Figure 5. The unit of speed is rpm and the included angles between every hall sensors are 2 π /12.

In the fuzzy PI controller which is based on the variable sampling model in this we use three fuzzy PI controllers to attain the robust motor control and also to reduce the speed error by using fuzzy logic controller and PI controller.

3.1 BLDC Motor

In continuous time model of the BLDC motor, create transfer functions of BLDC motors according to the motor rating,

$$J\omega + D\omega = T_{e} - T_{l} \quad (1)$$

$$T_{e} = K \cdot I \quad (2)$$

$$V = RI + L\, {}^{di}/_{dt} + K_{e}\,\omega$$

$$\omega/V = K_{t} / (L_{s}+R)\,(J_{s}+D) + K_{t}K_{e}$$

Where ω is motor speed, T_e = 0.28383 V-s/rad is electromagnetic developed torque, T_l = 0.392 Nt-m is load torque, K_t = 0.28383 V-s/rad is torque constant, K_e is back-emf constant, L = 24 mH is armature inductance, I = 1A is armature current, V is terminal voltage, and R = 5.17 ohms is terminal resistance.

3.2 Simulink Outputs

The simulation result shown in Figure 8. The fuzzy PI controller which is based on the variable sampling effect, the speed will be varies according to the command is from 500 rpm to 1500 rpm, and up to 2500 rpm. This effect has the fast and stable response for low, medium and high speed Command.

4. Conclusion

This paper proposes a fuzzy PI controller for BLDC motor drives with low resolution position sensors (Hall sensors). In this we use three fuzzy PI controllers to reduce the speed error. The sampling time which will be variable with respect to the motor speed in the BLDC drives. In this by using the variable sampling effect the response time taken to attain its speed of the motor is low whereas, response time is high, where as in PI controller the response time is low when compared to the fuzzy PI controller.

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