Comparison of PI, PID Controller and Fuzzy PI Controller for BLDC Speed Control Application

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Abstract— This paper presents comparison between PI and PID controllers for speed control of BLDC motor. A BLDC motor is superior to a conventional DC motor, because it replaces the mechanical commutation with electronic commutation; thus improving the dynamic characteristics, efficiency and reducing the noise level. In many industrial applications conventional PI controller is used for speed control. But for many sophisticated applications this controller response is not efficient. So as a better choice, a fuzzy logic control technique is applied to this motor to achieve a greater accuracy in controlling the speed. Simulation is carried out in MATLAB/SIMULINK. A comparison is done between existing PI and PID controller and the fuzzy PI controller for the speed control application.
Key words: Fuzzy PI control, Speed Control, PI controller, PID controller, Hybrid Controller, BLDC

I. INTRODUCTION

The electric drives with new technologies are developed each day. With the advancement in technology, there are different kinds of drives available. Generally, a high performance motor drive system with good dynamic response is required to perform the tasks. Conventional DC motors have excellent characteristics such as favourable cost, high reliability and flexibility etc.

But regular maintenance, frequent replacement of brushes, high initial cost etc. are its disadvantage. The alternative to the conventional DC motor is the squirrel cage induction motor. The squirrel cage induction motor offers robustness with low cost however, its disadvantages are poor starting torque and low power factor [1]. Moreover, for high speed applications neither conventional DC motors nor induction motors can be used. To overcome the disadvantages of the conventional DC motors and induction motors brushless DC motors can be used for such applications.

BLDC motors are gaining wide popularity because of its simple structure, small size, high reliability and high torque. It finds applications in automobile, automation, consumer electronics, medical, electric vehicle and industrial applications due to their high efficiency, long operating life ratio of torque delivered to the size and fast dynamic response due to their high efficiency, long operating life ratio of torque delivered to the size and fast dynamic response.

Therefore a more accurate speed control is needed. The speed of the motor is generally affected due to sudden change in load or speed. Hence to prevent this sudden change in speed, controllers have to be designed. In this paper, a comparison is done with PI, PID and fuzzy PI controllers.

The process of changing the electric power delivered to the motor to achieve a certain speed which is needed is called speed control. Another purpose of speed control is to keep the motor speed constant with outsource disturbances in torque. There are three different controllers discussed in this paper- PI controller, PID controller and fuzzy PI controller and a comparison is carried out.

II. CONVENTIONAL PI CONTROLLER

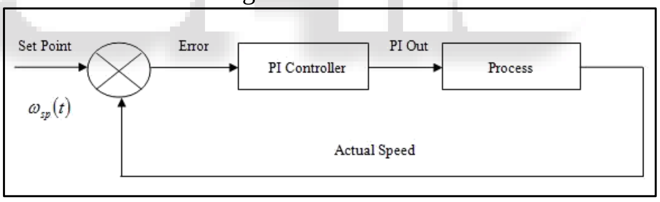
The aim of any controller is to reduce the error between the actual output (to be controlled] and the desired output 9set point] [3]. The error equation for speed control is given as:

$$e(t) = \omega_{sp}(t) - \omega_{pv}(t) \quad (1)$$

Where e(t is the error function of time, $\omega_{sp}(t)$ is the reference speed as the function of time and $\omega_{pv}(t)$ is the actual motor speed as a function of time. The transfer function of the PI controller can be expressed as:

$$u(t) = K_p e(t) + K_i \int e(t)dt \quad (2)$$

Where $u(t)$ is the PI output, K_p is the proportional gain, K_i is the integral term. The function of the PI Controller is shown in the block diagram below:



The actual speed, $\omega_{pv}(t)$ of the motor is compared with the reference value, $\omega_{sp}(t)$ and the error signal is given to the PI controller. The PI controller output is given to the process to be controlled.

There are four main parameters which should be minimized by the control system according to [4]. They are:

1) Rise Time: the time taken for the plant output to rise beyond 90% of the desired level for the first time.
2) Overshoot: how much the peak level is higher than the steady state, normalized against the steady state.
3) Settling Time: the time it takes for the system to converge to its steady state.
4) Steady-state Error: The difference between the steady state output and the desired output.

The proportional mode controls instant speed error and integral term mode determines the reaction based recent error [5]. These two modes control the speed. For many industrial drives PI controller is a good choice. But a very accurate speed control is not obtained in PI controller. During initial starting conditions, some speed oscillations may occur, which damps out with time. And also if in steady state conditions, if the load changes then speed also vary. Because of this limitation of the PI Controller other controllers like PID Controllers and Fuzzy PI controllers are used.

III. CONVENTIONAL PID CONTROLLER

The transfer function of the conventional PID controller is:

$$K_s = K_p + \frac{K_i}{S} + K_d S$$

Where, K_p, K_i and K_d are proportional gain, integral gain and derivative gain respectively. Each part of the controller performs specific function. The proportional part reduces the error responses of the system to disturbances, the integral part eliminates the steady-state error, and finally the derivative part dampens the dynamic response and improves the system stability [4th reference from first paper]. These parameters should be chosen such that it is suitable for the plant. For designing a PID controller, the various steps are:

1) Determine what characteristics of the system needs to be improved.
2) Use KP to decrease the rise time.
3) Use KD to reduce the overshoot and settling time.
4) Use KI to eliminate the steady-state error.

There are many methods to determine these parameters. Some of them are: trial and error method, Ziegler- Nichols (ZN) method and genetic algorithm technique. But these methods cannot guarantee to be effective always and also due to sudden variation in speed and load these parameters get altered all the time so to prevent this variation fuzzy PID controllers are to be used. Also the settling time is reduced in fuzzy PID controller.

IV. FUZZY PI CONTROLLER

The term ‘fuzzy’ means vagueness. This logic was developed by Lotfi Zadeh. Fuzzy systems are rule based systems. The Fuzzy PI used in this paper is realised using two inputs: Error (E) and Change in Error (CE). This is shown below:

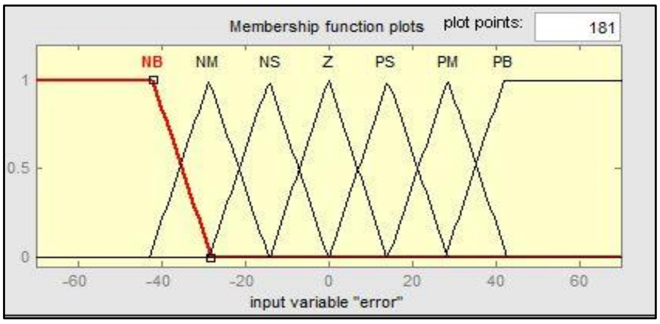


Fig. 2: Input membership functions for error

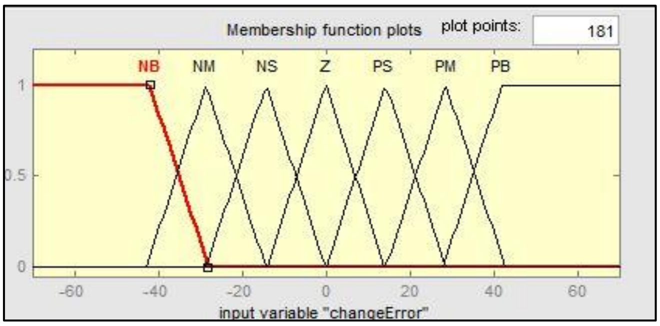


Fig. 3: Input membership function for change in error

The output graph is shown below:

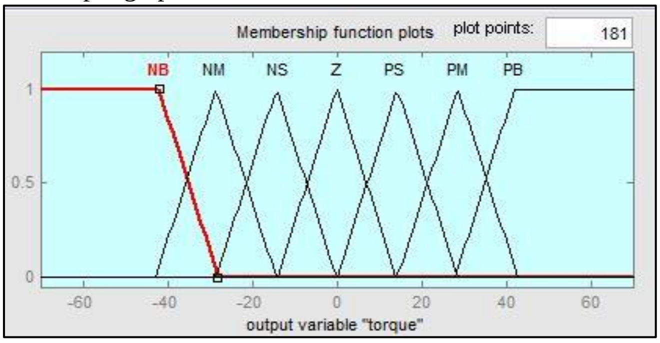


Fig. 4: Output membership functions

The membership functions used are: Positive Big (PB), Zero (Z), Positive Small (PS), Positive Medium (PM), Negative Medium (NM), Negative Small (NS) and Negative Big (NB). The input parameters, error and delta error or change in error are the inputs to the fuzzy system and output can be called as modulation or torque. The fuzzy rules are formulated using the AND operation with the two inputs.

The advantage of using hybrid controller (Fuzzy PI) controller is settling time of the BLDC speed graph is reduced to a small value and noise is also less. The speed control is obtained by comparing the reference voltage to the actual voltage of the converter output and the error signal is given to the gate of the converter. Since voltage is proportional to speed in BLDC, speed increases when voltage increases. In this paper, speed control is obtained from 217 rpm -317 rpm, with the reference voltage varying from 20 V to 30 V. This low speed of BLDC can be used in aerospace application [5].

V. SIMULATION OF BLDC SPEED CONTROL USING PI CONTROLLER

Most industrial applications do not use the derivative part in the PID. In this paper a PI controller is proposed. The BLDC motor used is a 24V, 60W, 4000rpm. The used PI coefficients are as follows: $K_P = 0.1$ and $K_I = 1$. The simulation model is shown below:

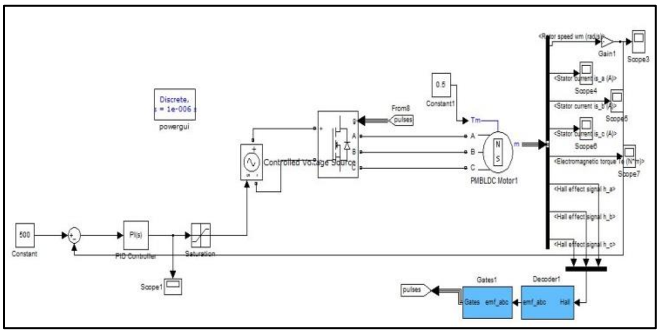


Fig. 5: Simulation Model of BLDC motor using PI controller

The speed response of the system is shown below:

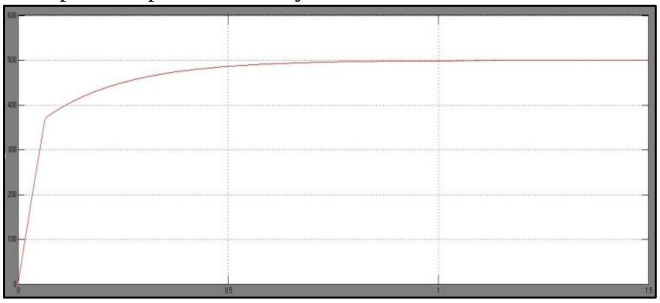


Fig. 6: Speed response of the system

From the speed response it can be seen that initially the speed starts from zero. At 0.002 sec, the speed rises to 380 rpm. After this time, the speed again rises and reaches the reference speed. At 0.8 sec the speed settles to the reference speed of 500 rpm. Hence the settling time of the system is too long. Also in steady state conditions if the load changes then speed fluctuations are produced in the system. To overcome this disadvantage of the controller, advanced controller like the PID and fuzzy PI controller is used.

VI. SIMULATION OF BLDC SPEED CONTROL USING PID CONTROLLER

The PID controller has the derivative term incorporated into the system. The PID parameters used are $K_P = 0.1$, $K_I = 1$ and $K_{d=}0.02$. The simulation model of the system is shown below:

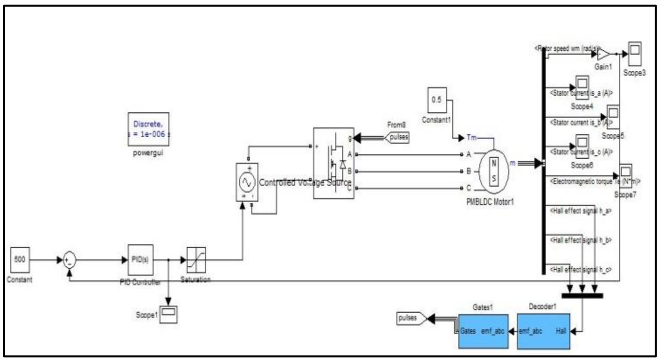


Fig. 7: Simulation Model of BLDC motor using PID controller

The speed response of the system is shown below:

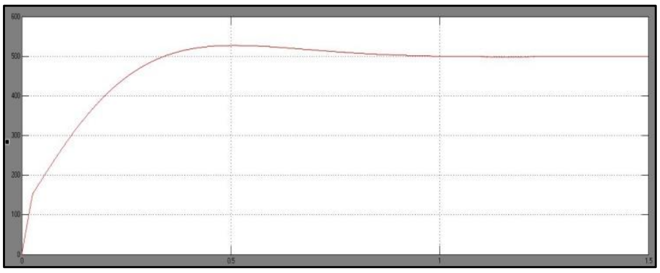


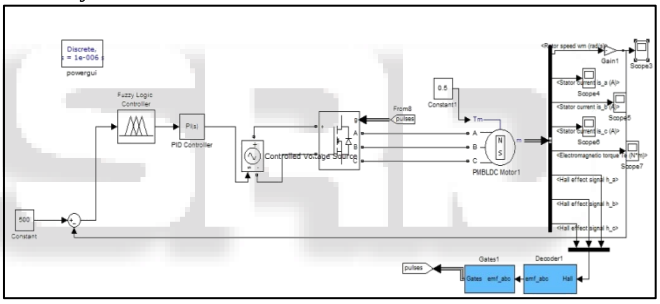
Fig. 8: Speed response of the system using PID controller

It can be observed that the speed starts from zero. The speed response has overshoot present when PID controller is used compared to when there was no overshoot present when PI controller is used. The settling time of the system is around 0.8 sec taken to reach 500rpm.

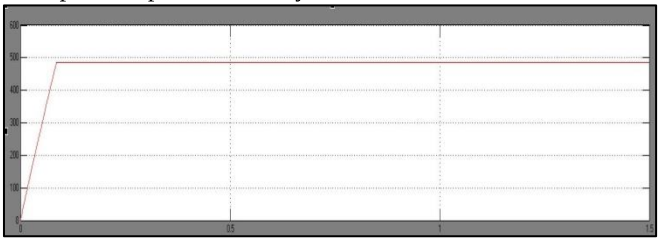
But this controller cannot be used much in industrial applications due to the presence of the derivative term. This derivative term contributes to the production of noise in the system. To overcome this controllers like fuzzy PI has to be incorporated.

VII. SIMULATION OF BLDC SPEED CONTROL USING FUZZY PI CONTROLLER

Fuzzy PI controller is the most commonly used controller for precise speed control applications. The simulation model of the system is shown below:



The speed response of the system is shown below:



It can be seen that speed starts from 0. The settling time is reduced to a very small value when compared to PI and PID controllers. The speed response of the system settles to 0.02 sec.

VIII. CONCLUSION

It can be seen from the discussion that fuzzy PI controllers have advantages over the conventional PI and PID controllers and are used widely. Also fuzzy PI controller is not affected whenever there is variation in speed or load. It is also used in those system where obtaining a mathematical model becomes difficult. Hence fuzzy PI controller is used widely.

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