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Comparative analysis between Digital PWM and PI with Fuzzy Logic Controller for the speed control of BLDC Motor

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Abstract: BLDC motor is widely used in industries because high efficiency, low cost, and roughest construction. This paper proposed the method of comparative analysis between DPWM and PI with Fuzzy logic for the speed control in BLDC motor. Speed control is a challenging area of research due to its importance to variety of commercial applications. Speed control systems are widely implemented in automatic speed control of machine at industries. The overall problems are subdivided into two key modules, (a) Proportional Integral, & (b) Fuzzy logic controller. A Brushless DC (BLDC) drives are known for higher efficiency, lower maintenance and higher cost. In this paper presents a proposed method for speed control of BLDC motor using Digital PWM and PI with Fuzzy logic controller. This digital control treats BLDC motor as a digital system and regulates speed with the help of two predefined state variables techniques, which makes the concept of controller extremely simple for design and implementation. The main disadvantage of DC motor is sparking problem in brush but if using BLDC motor solve this problem. PI with Fuzzy is very nice and good concept for speed control of motor because this concept is combination of convention and modern technique. The key advantage of Fuzzy logic controller is switching is possible at different stage, and key advantage is change the value of P and I and regulate the speed of motor. The main advantage of Digital PWM is control the speed without change the voltage and current that's why only change the width of plush and reduce the losses related to current.

Keywords: BLDC Motor, Digital Pluse Width Modulation, PI Controller, Fuzzy Logic Controller.

Introduction

BLDC motor provides the advantage brushed DC motor. In terms of variable speed operation but without the drawback of brushes & electronic controller is used to control the electrical current following in the motor. BLDC motor is in widespread used in computer disk drive and are also use in high performance motion control products such, as machine tools. The general trends of following cost of electronic products and the increased in use of microprocessor to control the performance of machine & application is leading to increased interest in the use of BLDC motor. Typically, machines found in these appliances are single phase induction motors or brushed dc machines which are characterized by low efficiency and high maintenance, respectively [6]. Replacing these inefficient motors with more efficient brushless dc (BLDC) motors will result in substantial energy savings. Proportional-integral (PI) control with hysteresis or pulse width modulation (PWM) switching is the most widely used speed control technique for BLDC motors with trapezoidal back EMF. It can be easily implemented on analog or digital components because it is well understood, simple, and in practice for a fairly long period of time. In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection. Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of fl. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multivalve logical systems.

Controller Design for DPWM

The value of the duty ratio D can be obtained from the electrical and mechanical equations [1]. The value of D can be expressed as a function of the motor parameters.

$$T_{em=J\frac{dw}{dt}+Bw+Tl} \text{ ....1}$$

$$T_{em} = \text{Ktl} \text{ ....2}$$

Where *Te*, w(t), *B* , *J* and *TL* denote developed electromagnetic torque, rotor angular velocity, viscous friction rotor moment of inertia and load torque respectively. Equate (1) and (2), we get J

$$\text{Ktl} = J\frac{dw}{dt} + Bw + Tl \text{ ....3}$$

where *Kt* = torque constant and *I* = average current. At steady state, (3) can be written in terms of steady-state angular velocity Wss as

$$I_{wss} = \frac{1}{kt} + (Bwss + Tl) \text{ ....4}$$

At steady state angular velocity *Wss* , phase voltage *Van* can be expressed in terms of phase current I, winding resistance and velocity constant *ke*, ie given by

$$\text{Van} = \text{Ira+KeWss} \text{ ....5}$$

The phase voltage in terms of dc-link voltage *V*dc and duty ratio *D* is

$$\text{Van} = \text{DVdc} \text{ ....6}$$

Substituting the value of the steady-state current from (4) and phase voltage from (6) in (5),we get the value of duty ratio

$$D = \frac{1}{V_{dc}}\left[\frac{(Tl+Bwss)}{Kt} + Kewss\right] \text{............7}$$

By considering *WL* and *WH* we can get the *DL* and *DH* respectively. The maximum deviation from the reference speed (*W**) due to the application of high duty *DH* is denoted by *ΔωH*, and the maximum deviation from the reference speed due to the application of a low duty *DL* is denoted by *ΔωL*. The speed response can be expressed as

$$w_{(t)} = \frac{Tem-Tl}{B} + \left[w - \left(\frac{Tem-Tl}{B}\right)\right]e^{\left(\frac{-1}{B}\right)t} \text{ ......8}$$

Controller Design for PI with Fuzzy Controller

The PI control problem has to be converted form a theoretical continuous process into a real "discrete" system running on a microcontroller. What this mean in practice is that the measuring of the set point and motor speed and the calculation of the output is only performed a regular interval. In the context of a microcontroller, this is might correspond to some code run from a timer interrupt.

The PI controller can thus be expressed as: Output = Proportional Gain*(error_speed) + Integral Gain*S (previous_error_speed_) and **Final output** = [{(Output) or Proportional Gain*(error_speed) + Integral Gain*S (previous_error_speed_)} – (last_error_speed)]

PI Error Calculation:

The PI controller compares the set point (SP) to the process variable (PV) or mean variable (MV) to obtain the error e, as follows:

$$e = SP - PV \qquad 9$$

Then the PI controller calculated the control action, u (t), as follows. In this equation, Kp is the process gain.

$$u = K_p e + \frac{1}{\tau_I}\int e \, d\tau \qquad 10$$

Where τ_I = "Integration time"

The above following formula represents the proportional gain.

$$Up(t) = Kp(e) \qquad 11$$

Implementing the PI Algorithm with the PI Functions:

This section describes how the PI control toolbox function implements the PI algorithm. The PI algorithm used in the PI control toolbox

Error Calculation

The following formula represents the current error used in calculating proportional, integral, where PV is the filtered process variable.

$$e(k) = SP - PV \qquad 12$$

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Proportional Action

Proportional action is the controller gains times the error, as show the following formula:

$$Up\ (k) = Kp^{*}\ e\ (k) \qquad 13$$

Trapezoidal Integration

Trapezoidal Integration is used to avoid sharp changes in integral action when there is a sudden change in the PV or SV. Use nonlinear adjustment of the integral action to counteract overshoot The following formula represents the trapezoidal integration action.

$$Ui\ (k) = Kp/Ti\Sigma\ \{[e\ (i) + e\ (i-1)]/2\}\ \Delta t \qquad 14$$

Where i = 1, 2, 3 …k

Controlled Output

Controller output is the summations of the Proportional, and integral action, as show in following formula:

$$U\ (k) = Up\ (k) + Ui\ (k) \qquad 15$$

Output Limit:

The actual controlled output is limited to the range specified for control output as follows:

If U (k) ≥ Umax then U (k) = Umax

And

If U (k) ≤ Umin then U (k) = Umin

The following formula shown the practical model of PI controller

$$U\ (t) = Kp\ [(SP-PV) + \frac{1}{T_i}\int_0^t (SP - PV)\ dt]$$

The PI function uses an integral sum correction algorithm that facilitates anti-windup & bumpless manual-to-automatic transfers. Windup occures at the upper limit of the controller output, for example, 100% when the error (e) decreases the controlled output is decreases, moving out of the windup area. The integral sum correction algorithm prevents abrupt controller parameters. The default range for the SP, PV and output parameter corresponds to percentage value; adjust the corresponding range accordingly.

Error Calculation:

The current error used in calculating integral action for the precise PI algorithm is shown the following formula:

$$e\ (k) = (SP-PV_f)(L+(1-L)^{*}\frac{|SP-PV_f|}{SP_{range}}) \qquad 16$$

Where SP range is the range of the SP and L is the linearity factor that produces a nonlinear gain term in which the controller gain increase with the magnitude of the error. If L is 1, the controller is linear. A valve of 0.1 makes the minimum gain of the controller 10% Kp. Use of a nonlinear gain term is referred to as a precise PI algorithm. Results shown in figure no. (2), and (3).

Design of the Fuzzy Logic Control Scheme:

Fuzzy controllers have got a lot of advantages compared to the classical controllers such as the simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the process. Fuzzy logic is one of the successful applications of fuzzy set in which the variables are linguistic rather than the numeric variables. Linguistic variables, defined as variables whose values are sentences in a natural language (such as large or small), may be represented by fuzzy sets. Fuzzy set is an extension of a ‘crisp’ set where an element can only belong to a set (full membership) or not belong at all (no membership). Fuzzy sets allow partial membership, which means that an element may partially belong to more than one set. A fuzzy set A of a universe of discourse X is represented by a collection of ordered pairs of generic element x ∈ X and its membership function μ : X → [0 1], which associates a number μ A(x): X → [0 1], to each element x of X.

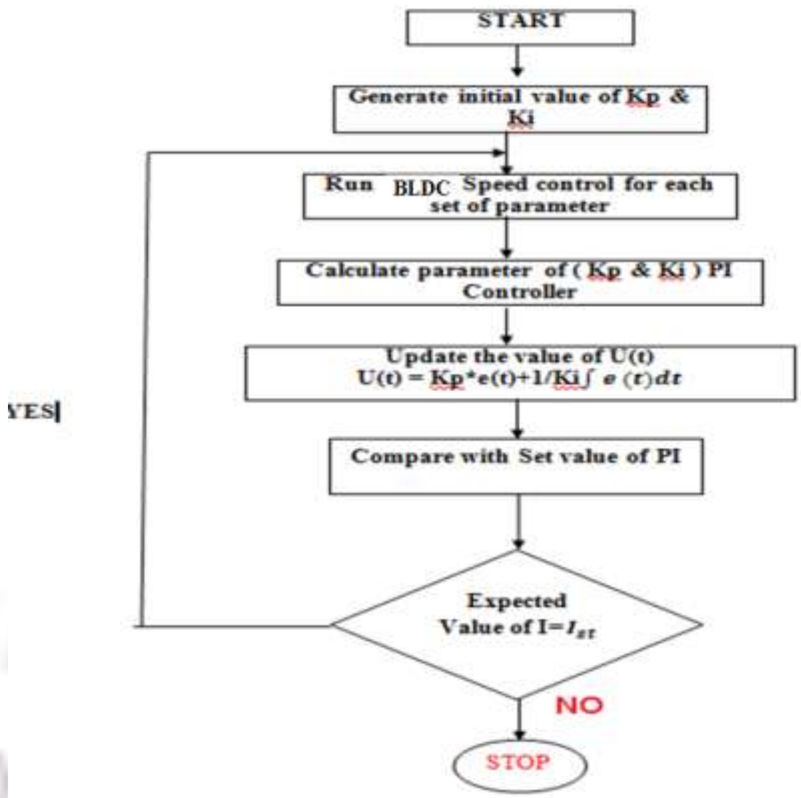

Fig. 1: Flow chart for speed control using PI controller

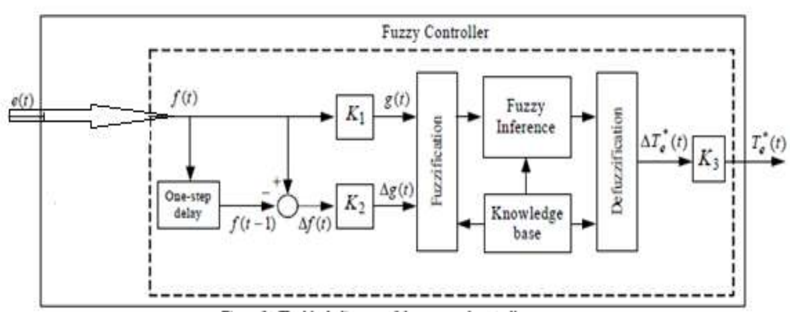

Fig. 2: Block Diagram of PI with Fuzzy Logic controller

Table 1. Fuzzy rule base

$g(t)$ / $\Delta g(t)$ / u	N	Z	P
N	b	b	b
Z	-b	0	b
P	-b	-b	-b

Fig. 3: Rule Base for Fuzzy logic controller

$$\mu_N(x) = \begin{cases} 1 & x \le -b \\ \frac{-x}{b} & -b < x \le 0 \\ 0 & \text{otherwise} \end{cases}$$

$$\mu_Z(x) = \begin{cases} \frac{x+b}{b} & -b < x \le 0 \\ \frac{b-x}{b} & 0 < x \le b \\ 0 & \text{otherwise} \end{cases}$$

$$\mu_P(x) = \begin{cases} 1 & b \le x \\ \frac{x}{b} & 0 < x \le b \\ 0 & \text{otherwise} \end{cases}$$

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The fuzzy inference engine, based on the input fuzzy sets in combination with the expert's experience, uses adequate IF-THEN rules in the knowledge base to make decisions and produces an implied output fuzzy set u . For this particular application, the proposed IF-THEN fuzzy rule base is shown in Table 1 and is described as follows:

i. If $\Delta g(t) \in$ N, then $u(g(t), \Delta g(t)) = b$.

ii. If $\Delta g(t) \in$ P, then $u(g(t), \Delta g(t)) = -b$.

iii. If $\Delta g(t) \in$ Z and $g(t) \in$ N, then $u(g(t), \Delta g(t)) = -b$ ..

iv. If $\Delta g(t) \in$ Z and $g(t) \in$ P, then $u(g(t), \Delta g(t)) = b$.

v. If $\Delta g(t) \in$ Z and $g(t) \in$ Z, then $u(g(t), \Delta g(t)) = 0$.

Simulation and Results

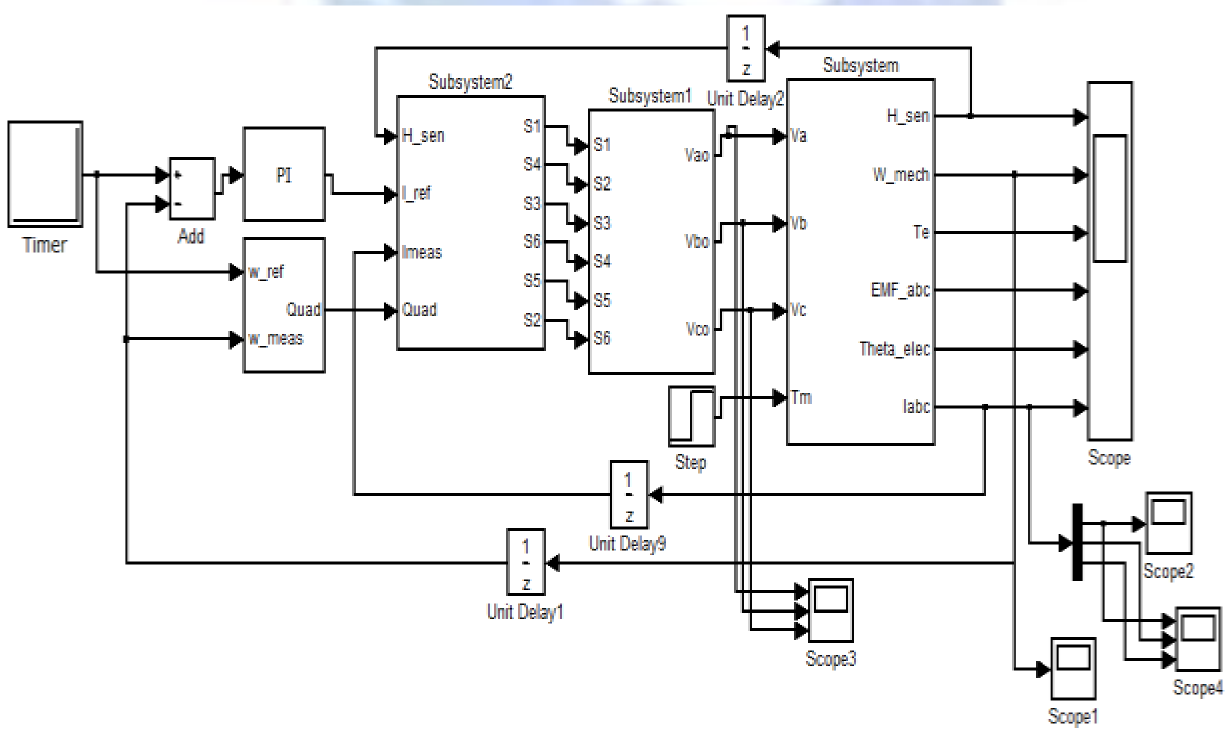

Fig. 4: Simulink model for speed control of BLDC motor using DPWM

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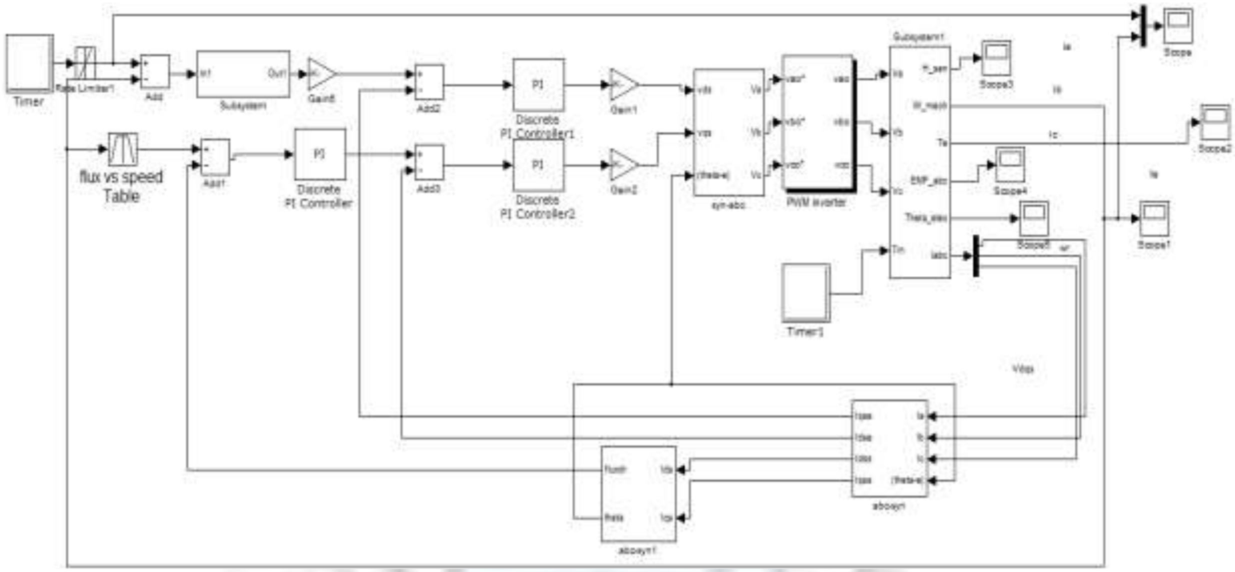

Fig. 5: Simulink model for speed control of BLDC motor using PI with FLC

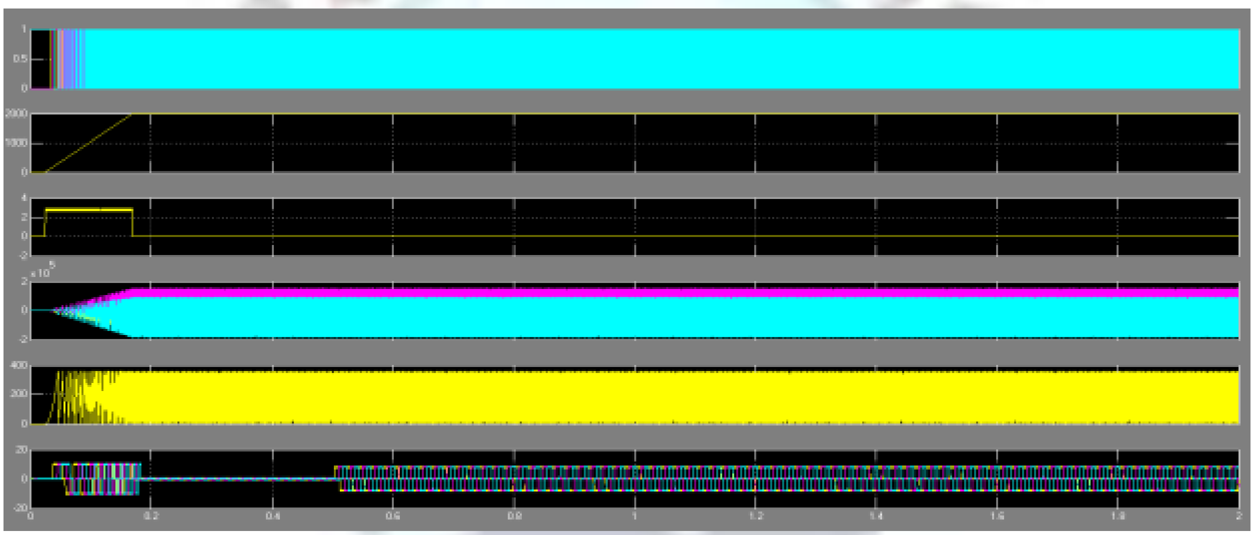

Fig. 6: Speed control of BLDC motor using DPWM

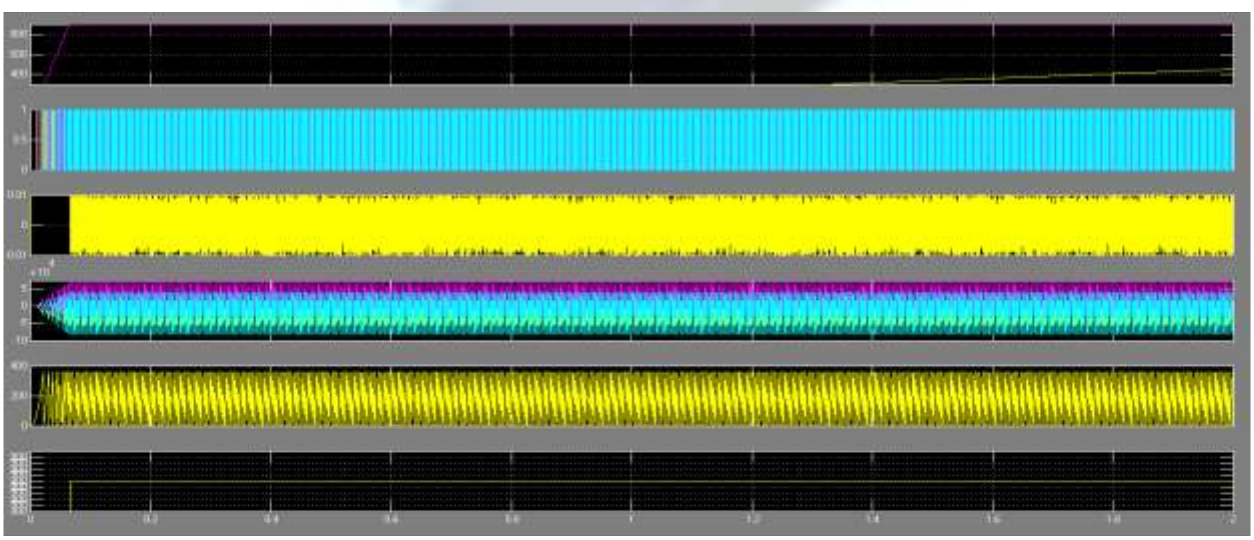

Fig. 7: Speed control of BLDC motor using PI with FLC

CONCLUSION

In this paper, comparing of the results between DPWM and PI with FLC of BLDC motor has been performed, If we apply the DPWM and change the width of frequency and regulate the speed. Another method is PI with FLC in this method. Change the parameter and regulate the speed, and FLC for switching purpose. Check out the results and decided PI with FLC is motor better as compare to the DPWM.

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