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THE DESIGN OF THE HYBRID PID-ANFIS CONTROLLER FOR SPEED CONTROL OF BRUSHLESS DC MOTOR

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ABSTRACT

This paper presents the design of the hybrid PID-ANFIS controller for controlling the speed of the Brushless Direct Current Motor (BLDCM). The objective of this work is to obtain the BLDCM speed controller equipment effectively. The hybrid PID-ANFIS controller is a combination of classical PID controller and ANFIS controller. This method is applied to BLDCM speed controller by simulation and implementation with making its prototype. Hybrid PID-ANFIS controller input consists of speed setting, actual speed and error speed. The actual speed is acquired the processing the rotor position sensor output signal. PID controller parameters are tuned using closed loop Ziegler Nichols method, while ANFIS controller parameters are acquired by off-line hybrid training. ANFIS training data includes the training input data (actual speed and speed setting) and target of ANFIS training (BLDCM input voltage in the form of PWM). The parameters of hybrid PID-ANFIS controller are the combination of the parameter of PID and ANFIS, added by the error limit. The error limit is functioned to select of working domain of each controllers through determining weight of PID and ANFIS activation signal that presented by a linear curve. The development of prototype is implementation from the development of structure and parameter of hybrid ANFIS-PID controller that uploaded into microcontroller ARM cortex STM32 F103RB using C programming language. The controller performance was analyzed based on speed response parameters, control energy and Integral Square Error (ISE) through testing each controller structure at various loaded and non-loaded conditions speeds setting. The testing results are obtained the best response performance that impacted to improve control energy reduction 17.36% and ISE 15.29%, the controllers can operate on a wide speed setting spectrum.

Keywords: *BLDCM, Speed control, Hybrid PID-ANFIS*

1. INTRODUCTION

Brushless Direct Current Machines (BLDCM) have advantages compared to induction motors and Conventional Direct Current Motors (CDCM). BLDCM have a 13% greater efficiency than induction machines and 40% smaller dimensions than CDCM [1]. Another advantage is that they can produce a large torque [2][3].

The response performance can contribute to energy efficiency. A good response of the controller's performance can decrease energy consumption [4]. The problem lies in the BLDCM speed controller instrument, which still has its limits. The classic PID (Proportional Integral Derivative) controller is commonly found in industry, i.e. almost 90%, because it is simple and it is able to improve the transient response by tuning the PID parameters appropriately, i.e. K_p, K_i and K_d [5]. Fuzzy Logic Controller (FLC) works based on fuzzy logic rules, which represent the thinking process of an excellent operator when controlling a plant. The response performance of an FLC controller depends on determining the function and domain of the input/output membership functions appropriately. The problem is, therefore, to determine the appropriate domain of input and output membership functions, and the residual oscillations at steady state response [6]. Adaptive Neuro Fuzzy Inference Systems (ANFIS) are an adaptive network based on the fuzzy inference system which works by adjusting the value of the weight of the. The network weights are determined by a training process, which result in the premise parameters and the consequence parameters. These represent the restriction of domain of membership function input network [7]. However, in order to develop a technique for implementing the ANFIS algorithm in a microcontroller which has limited memory capacity and numerical data processor speed, a separate study is needed.

The development of a control method which combines two or more controller methods is called a hybrid controller. The control method for the BLDCM speed control using PI, PID, PI-like FLC, FLC hybrid (HFLC) and integrated FLC (IFLC). These methods were evaluated by using MATLAB Simulink, and the speed responses of IFLC and HFLC controllers obtained were better than others [8]. The combination of the PI controller and fuzzy controller connected in parallel. It is called the hybrid PI fuzzy controller. A fuzzy controller is operated in a large speed error region, while a PI is operated in a small speed error region [9]. The classic PID controller and fuzzy PID controller (FPID) are combained that became known as a hybrid fuzzy PID controller (HFPID) [10]. The function of each controllers is classified based on the domain of speed error. The classic PID controller is operated in normal condition, while an FPID controller is operated in oscillation and overshoot condition. Aplliying the hybrid adaptive neural-fuzzy tuned P.I controller based unidirectional boost P.F.C converter feed BLDC drive [11].

The analysis and technique combine the PID and ANFIS controllers, called the hybrid PID-ANFIS, to control the speed of a BLDCM which are a major focus in this current study. The method applied will be the use of a microcontroller ARM Cortex-M3 which has sufficient capacity and capability to solve computational intelligent control algorithm, yet is cheap and readily available [12].

2. ANFIS AND PID CONTROLLERS

2.1. ANFIS Controller

A typical architecture of an ANFIS which is used is Sugeno fuzzy models consist of five layers that every layer has the node. There are two kind of nodes that called the adaptive node (square symbol) and fixed node (circle symbol) as shown Figure 1. The mechanism is designed using Sugeno with has two inputs x_1 and x_2 and one output y. For a first-order Sugeno fuzzy model, a common rule set with two fuzzy if-then rules the folowing [7].

If x_1 is A_1 and x_2 is B_1 Then $y_1 = c_{11}x_1 + c_{12}x_2 + c_{10}$
If x_1 is A_2 and x_2 is B_2 Then $y_2 = c_{21}x_1 + c_{22}x_2 + c_{20}$ (2)

If α is predicated for two roles are w_1 and w_2, then can be determined the weight average as below

$$y = \frac{w_1 y_1 + w_2 y_2}{w_1 + w_2} = \overline{w_1} y_1 + \overline{w_2} y_2 \quad (3)$$

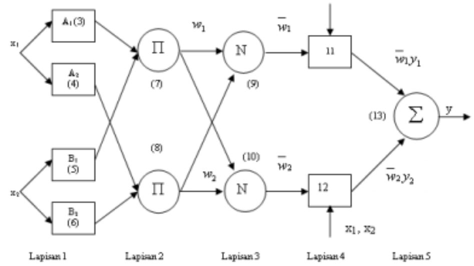


Figure 1: The architecture ANFIS

The layer function:

Layer 1

Every node i in this layer is an adaptive node which a node activation function parameter. The output of every node is the membership function degrees which given by input membership function as the following

$\alpha_{A1}(x_1), \alpha_{B1}(x_2), \alpha_{A2}(x_1)$ or $\alpha_{B2}(x_2)$.

$$O_{1,i} = \mu_{Ai}(x_1), \text{ for i = 1, 2, or}$$
$$O_{1,i} = \mu_{Bi}(x_2), \text{ for i = 3, 4,} \quad (4)$$

If membership function is given by the generalized bell function as below

$$\mu(x) = \frac{1}{1 + \left| \frac{x-c}{a} \right|^{2b}} \quad (5)$$

where {a,b,c} are the parameter set. As the value of these parameters changes, the bell-shaped function varies accordingly, thus exhibiting various forms of membership functions for fuzzy set A. Parameters in these layers are referred to as premise parameters.

Layer 2

Every node in this layer is fixed node is labeled Π, whose output is the product of all the incoming signals as below

$$O_{2,i} = w_i = \mu_{Ai}(x_1) x \mu_{Bi}(x_2), \text{ for i = 1, 2} \quad (6)$$

Each node output represents the firing strength (α predicate) of a rule. In general, any other T-norm that performs fuzzy AND can be used as the node function in this layer.

Layer 3

Every node in this layer is a fixed node labeled N. The i[th] node calculates the ratio of the gain ratio i[th] rule firing strength (α predicate) to the sum of all rules' firing strengths as below

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1 + w_2}, \text{ i = 1,2} \quad (7)$$

For convenience, outputs of this layer are called normalized firing strengths.

Layer 4

Every node i in this layer is an adaptive node with a node function is

$$O_{4,i} = \overline{w}_i y_i = \overline{w}_i (c_{i1}x_1 + c_{i2}x_2 + c_{i0}) \quad i = 1,2 \qquad (8)$$

where $\overline{w}_i$ is a normalized firing strength from layer 3 and $\{c_{i1}, c_{i2}, c_{i0}\}$ are the parameter set of this node. Parameters in this layer are referred to as consequent parameters.

Layer 5

The single node in this layer is a fixed node labeled Σ, which computes the overall output as the summation of all incoming signals as following

$$O_{5,i} = \sum_i \overline{w}_i y_i = \frac{\sum_i w_i y_i}{\sum_i w_i} \qquad (9)$$

The parameter to be trained are a, b and c of the premise and c_{i1}, c_{i2} and c_{i0} of the consequent parameters. ANFIS is trained using hybrid learning algorithm that consists of two steps such as feed forward pass and backward pass. More specifically, in the forward pass of the hybrid learning algorithm, node outputs go to forward until layer 4 and consequent parameters are identified by the least squares method. In the backward pass, the error signal propagates backward and the premise parameters are updated by gradient descent.

2.2 PID Controller

The PID controller is defined by the following relationship between the controller input (e) and the controller output (u) that is applied to motor armature [5].

$$u = K_p e + K_i \int e dt + K_d \frac{de}{dt} \qquad (10)$$

To discredits the controller is given as

$$\frac{du}{dt} = K_p \frac{de}{dt} + K_i \frac{d}{dt}\left(\int e.dt\right) + K_d \frac{d^2 e}{dt^2} \qquad (11)$$

$$\frac{du}{dt} = K_p \frac{de}{dt} + K_i e + K_d \frac{d}{dt}\left(\frac{de}{dt}\right) \qquad (12)$$

the time rate $\frac{d}{dt}$ is represented by $\frac{\Delta}{T_s}$ thus:

$$\frac{\Delta U}{T_s} = K_p \frac{\Delta e}{T_s} + K_i e + K_d \frac{\Delta}{T_s}\left(\frac{\Delta e}{T_s}\right) \qquad (13)$$

$$\Delta U = K_p \Delta e + K_i e.T_s + K_d.\Delta\left(\frac{\Delta e}{T_s}\right) \qquad (14)$$

the error rate become:

$$\Delta e = e_n - e_{n-1} \qquad (15)$$

$$\Delta(e_n - e_{n-1}) = (e_n - e_{n-1}) - (e_{n-1} - e_{n-2})$$
$$= e_n - 2e_{n-1} + e_{n-2} \qquad (16)$$

The output rate is

$$\Delta U = U_n - U_{n-1} \qquad (17)$$

thus,

$$U_n - U_{n-1} = K_p.(e_n - e_{n-1}) + K_i.e_n.T_s + \frac{K_d}{T_s}.\Delta(e_n - e_{n-1}) \qquad (18)$$

Substituting (30) into (32) are obtained as

$$U_n = U_{n-1} + K_p.(e_n - e_{n-1}) + K_i.e_n.T_s + \frac{K_d}{T_s}.(e_n - 2e_{n-1} + e_{n-2}) \qquad (19)$$

where,

U_n : controller output

e_n : error

T_s : time sampling

3. PROPOSED HYBRID PID ANFIS CONTROLLER

The Hybrid PID-ANFIS controller is combining two controller modes such as PID controller and ANFIS controller. The structure of hybrid PID-ANFIS is shown in Figure 2. It works based on speed error to determine the operating domain of PID and ANFIS controllers. The activation signal of each controller is determined by the activation degree of PID and ANFIS controller,

$$U_{HYBRID} = \mu_1(x).U_{PID} + \mu_2(x).U_{ANFIS} \qquad (20)$$

where $\mu_1(x)$ is the activation degree of PID and $\mu_2(x)$ is the activation degree of ANFIS.

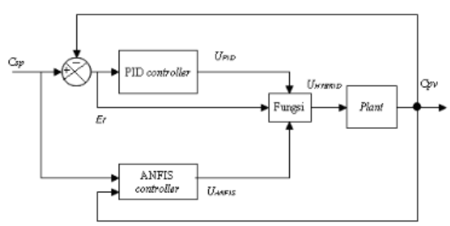


Figure 2: Block diagram of the hybrid PID-ANFIS controller

The activation degrees are calculated based on a speed error represented by x variable (E_{rss}) that represented by linier function. A PID controller operates in a large speed error domain, while an ANFIS controller operates in a small speed error domain. The operating domain of PID and ANFIS controllers is determined by a and b parameters that acquired base on the speed response at delay time, rise time and settling time as shown in Figure 3

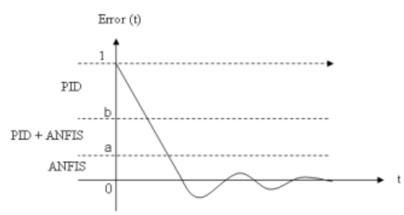
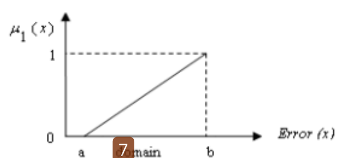


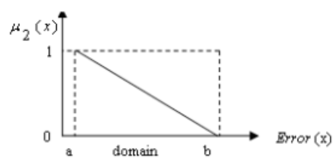
Figure 3: Controllers domain based on an error characteristic

Activation degree of PID controller ($\mu_1(x)$) and ANFIS controller ($\mu_2(x)$) are calculated based on the relation of speed error to linear curve as shown in Figure 4.



$$\mu_1(x) = \begin{cases} 0; \ldots\ldots\ldots\ldots x \le a \\ (x-a)/(b-a); \ldots a \le x \le b \\ 1; \ldots\ldots\ldots\ldots x \ge b \end{cases} \quad (21)$$

(a) PID controller



$$\mu_2(x) = \begin{cases} 1, \ldots\ldots\ldots\ldots x \le a \\ (b-x)/(b-a) \ldots\ldots a \le x \le b \\ 0, \ldots\ldots\ldots\ldots x \ge b \end{cases} \quad (22)$$

(b) ANFIS controller

Figure 4 : Represention of the activation degree of each controller

Flow chart of the hybrid PID-ANFIS controller structure are shown in Figure 5.

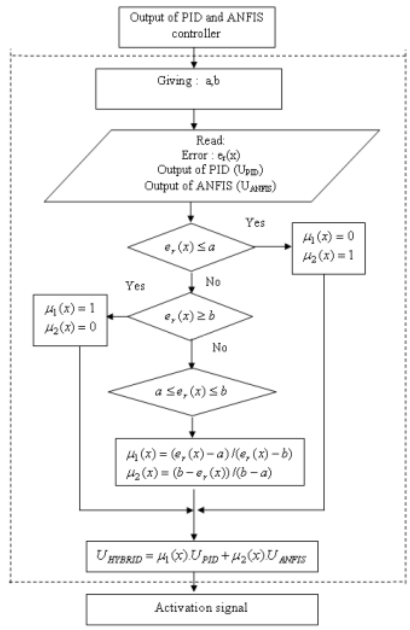


Figure 5: Flowchart of the selecting hybrid PID-ANFIS controller

4. HARDWARE SYSTEM DESCRIPTION

Generally, BLDCM is constructed of the Permanent Magnet Synchronous Machine (PMSM) 3 phase star connection, 2 poles, a AC source and rectifier, a rotor position sensor, 3 phase inverter and an algorithm control as shown in Figure 6 [13]. In practice, a BLDCM have been completed by those elements which generally consist of two parts of separate elements, such as a BLDCM driver and a BLDCM.

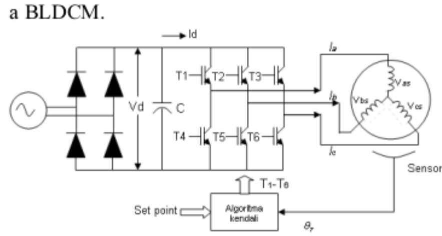


Figure 6 : The circuit element of BLDCM

The hardware apparatus for speed control BLDCM is composed of four major elements: an ARM Cortex-M3 board, controlled process (BLDCM ZW60BL120-430 with PM dc generator as dynamic load), a BLDCM driver 10/50DPW15B and a speed sensor. The ARM Cortex-M3 chips type STM32 F103RB M3 32 bit speed 72 MHz that forms the core of the closed loop system [12]. Aside from the duties of controlling the operator interface, it performs the acquisition of the feedback signal, computes an error signal, delivers the error signal to the control algorithm, and executes the control algorithm to determine a control signal. The control algorithm is built within C programming on notebook, thus uploading to ARM Cortex-M3. The motor is a 250W, 3000 r/min, 48V, 7A which is a BLDCM ZW60BL120-430 type and the 10/50DPW15B motor driver board, which was manufactured by Jinan Keya Electronic Co. LTD [14]. It provides an analogue set value input 0–5V, thus results 3 phase ac voltage output 10–50V for dc voltage input 50V. The motor is also coupled with PM dc generator as dynamic load.

A speed sensor is built of with useful rotor position sensor signal (H_1,H_2,H_3), which built in a BLDCM. In addition to a signal conditioner, can be acquired a speed information of BLDCM. Figure 7 shows a signal conditioner circuit. It consits of two ex-or gates and f/v converter circuit (IC LM331). A speed sensor output is an analogue signal 0–5 V that the equivalent of speed 0–3000 r/min.

An auxialiary equipment is notebook Intel Pentium Dual CPU T2330 @ 1.60 GHz with Windows XP and stored oscilloscope. A photo of the experimental apparatus of the BLDCM speed control system as shown in Figure 8.

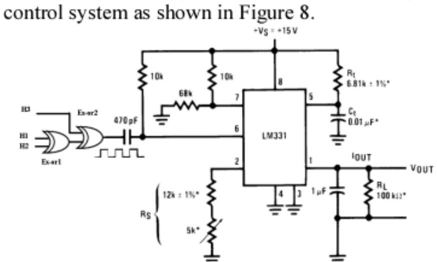


Figure 7: The signal condition circuit

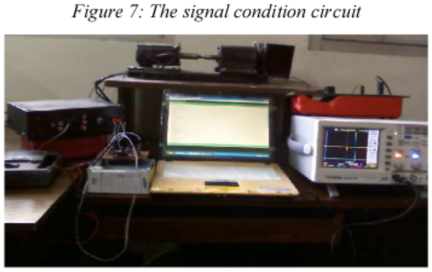


Figure 8: Photograph of the experimental apparatus.

5. EXPERIMENTAL RESULTS

In order to analyse the performance of the proposed hybrid PID-ANFIS controller, several test cases were completed in the laboratory under different control structure and speed setting for load and no-load condition. The control structure consists of three structures: the classical PID controller, the ANFIS controller and hybrid PID-ANFIS controller. The speed setting is 1500, 1800 and 2000 r/min. The standard PID controller is designed in accordance with the Ziegler Nichols tuning criteria. The best gains were found experimentally to be K_p=30, K_d=11, 25 and K =20 [14][15]

The parameter of ANFIS is determined by training process that needs three data such as two input data and an output data. The input data are actual speed and delay actual speed. The output data is a target which is the PWM signal data to the BLDCM driver input. The data for training are obtained from the open loop experiment, as shown in Table 1. The off-line training uses the MATLAB programming which is the bell function with 3 membership function for each input and output variables. The ANFIS used here contains 9 (3x3=9) rules, 45 total number of fitting parameters, including 18 (3x3+3x3) premise (non linier) parameters and 27 (3x9=27) consequent (linier) parameters. The training and root mean square (RMS) errors obtained from the ANFIS are 0,00072442 for 30 epochs. The premise parameter and consequent parameter are listed as in Table 2 and Table 3.

Table 1: The series data of ANFIS trainig

PWM (decimal)	Voltage control (V)	Voltage sensor (V)	Speed (r/min)
200	0.0	0.0	0,0
5000	0.4	1.2	648
10000	0.8	1.6	838
15000	1.0	1.8	1033
20000	1.3	2.1	1228
25000	1.7	2.4	1430
30000	1.8	2.6	1570
35000	2.0	2.9	1780
40000	2.3	3.1	1915
45000	2.5	3.2	2026
50000	2.7	3.3	2030
55000	3.0	3.3	2030
60000	3.2	3.3	2030
65000	3.4	3.3	2030

Table 2: The premise parameter of ANFIS

Premise Parameter	*Input_1* (r/min)	
	Before	After
a_1	747.5	747.5
b_1	2.0	2.0
c_1	-7.91	0.0
a_2	747.5	748.0
b_2	2.0	2.0
c_2	1495.0	1490.0
a_3	747.5	747.7
b_3	2.0	2.0
C_3	2990.0	2990.0
Premise Parameter	*Input_2* (r/min)	
a_1	747.5	747.5
b_1	2.0	2.0
c_1	10.0	10.0
a_2	747.5	747,5
b_2	2.0	2,0
c_2	1505.0	1505.0
a_3	747.5	747.7
b_3	2.0	2.0
c_3	3000.0	3000.0

Table 3: The consecuent parameter of ANFIS

Rule	Cons	Value	Rule	Concs	Value
	p_1	0.1897		p_6	0.1115
	q_1	19.8100		q_6	19.8900
1	r_1	1.9620	6	r_6	1.9780
	p_2	0.1360		p_7	1.9180
	q_2	19.8600		q_7	18.0900
2	r_2	1.9730	7	r_7	1.6170
	p_3	1.9180		p_8	0.1115
	q_3	18.0900		q_8	19.8900
3	r_3	1.6170	8	r_8	1.9780
	p_4	0.1360		p_9	0.1944
	q_4	19.8600		q_9	19.8100
4	r_4	1.9730	9	r_9	1.9610
	p_5	0.1791			
	q_5	19.8200			
5	r_5	1.9640			

The simulation test of the BLDCM speed control is proposed to obtain the PID and ANFIS parameters. While the hybrid PID-ANFIS parameters are the operating domain of PID and ANFIS controllers based on a speed error represented by values *a* and *b*. Determining of *a* and *b* parameters are based on the speed response at delay time, rise time and settling time conditions. The first step is made *a* = 32% to speed setting and *b* = 68% to speed setting. Furthermore, *a* = 5% and *b* = 95%. Finally, *a* = 0% and *b* = 100%. The results show that the best response was obtained at *a* = 0% and *b* = 100%. [15]

The first testing was done at a speed setting of 2000 r/min. The results are displayed in oscilloscope at a voltage scale (volt/div)=500 mv and a time scale (time/div)=1 second. The analisys of energy control and ISE is based on the controller output signal (v_t) and the error signal (e_t) respectively,

$$w = c\sum_{t=0}^{n} v_t^{\,2} \qquad ; t= 0, 1, 2....n \tag{23}$$

$$ISE = \sum_{t=1}^{n} e_t^{\,2} \quad , t = 1, 2, 3, ...n, \tag{24}$$

The experiment results of all control structure for a speed setting 2000 r/min is obtained a speed response. Furthermore, the speed respons of a PID, ANFIS and hybrid PID-ANFIS are drawn in the same axis which shown in Figure 9. The transient parameters of Hybrid PID-ANFIS controller i.e. t_r = 0.70 sec, t_s = 1.3 sec, M_P = 4.0%, E_{rss} = 0%, PID controller i.e. t_r = 0.7 sec, t_s = 1.5 sec, M_P = 8.0%, E_{rss}=2%, ANFIS controller i.e. t_r = 1.5 sec, t_s = 1.5 sec, M_P=0%, E_r=5%. The experiment results showed that the performance of hybrid PID-ANFIS controller is the best transient response than the others (PID or ANFIS). Energy control and ISE of the BLDCM speed controller are calculated by output signal (v_t) and the error signal (e_t) that aquired by measuring. The results are 60,425 and 36,255,000 respectively.

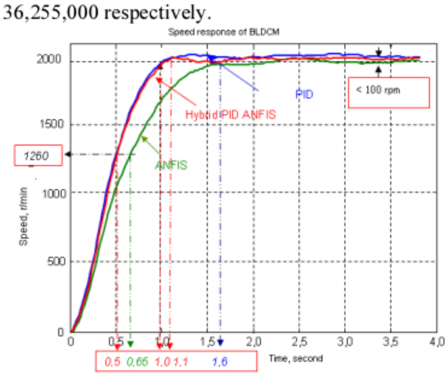


Figure 9: Speed response of a BLDCM speed control at speed setting 2000 r/min.

The others testing was done at set speeds of: 1800 r/min, 1500 r/min, 1200 r/min and 1000 r/min. The respons of speed setting 1200 r/min shown in

Figure 10. Speed response of PID controller required a residual steady state error. It is caused PID parameter that given unable to result controller signal to improve speed response as impact of a speed setting very widely. The transient parameter of speed response for all speed setting shown in Table 4.

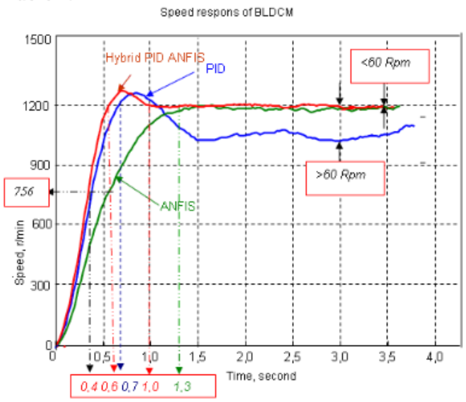


Figure 10: Speed response of a BLDCM speed control at speed setting 1200 r/min

Testing of a prototype *hybrid* PID-ANFIS as a speed controller for BLDCM is meant to test robustness of the controller when the BLDCM is loaded. The transient response of a BLDCM speed control for speed set at 1500 r/min is shown in Figure 11.

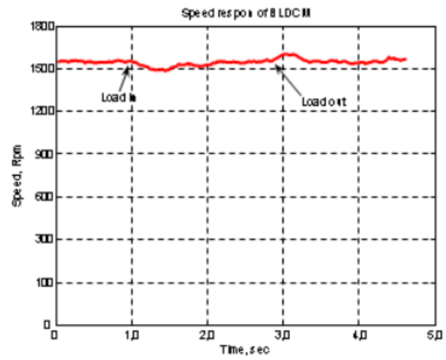


Figure 11 Transient response of BLDCM with load for speed set at 1800 r/min

The load is turned on at t = 1.5 second, which causes an undershoot of 5% for 0.5 second then after at t=3.5 second. The load is turned off which causes an overshoot of 5% for 0.5 second. The several tests done at speeds set at 1000 r/min, 1200 r/min, 1800 r/min and 2000 r/min, the parameters of transient are shown in Table 5.

Table 4:The parameters of transient, ISE and energy control of a BLDCM

Speed setting (r/min)	Controller structure	t_d (dt)	t_r (dt)	t_s (dt)	E_{rr} (%)	M_p (%)	ISE	$\sum_{t=0}^{n} v_t^2$
	Open loop	0,60	1,20	1,30	0,00	0,00	68.423	42.764.375
	PID	0,50	1,00	1,50	2,50	0,00	63.286	38.920.890
	ANFIS	0,65	1,60	1,60	0,00	0,00	64.578	39.069.690
2000	Hybrid PID-ANFIS	0,50	1,00	1,10	0,00	0,00	60.425	36.255.000
	Open loop	0,60	1,20	1,30	0,00	0,00	51.342	31.575.330
	PID	0,40	0,90	2,30	2,50	8,30	47.843	29.184.230
	ANFIS	0,60	2,30	2,30	3,00	0,00	48.614	29.411.470
1800	Hybrid PID-ANFIS	0,40	1,00	1,00	0,00	0,00	44.672	26.803.200
	Open loop	0,60	1,20	1,30	0,00	0,00	50.421	31.008.915
	PID	0,50	0,70	1,50	5,00	8,00	48.580	29.633.800
	ANFIS	0,75	1,60	1,60	0,00	0,00	47.986	29.031.530
1500	Hybrid PID-ANFIS	0,40	0,70	1,30	0,00	4,00	43.590	26.154.000
	Open loop	0,60	1,20	1,30	0,00	0,00	40.583	24.958.545
	PID	0,40	0,70	1,50	10,80	4,20	38.967	23.769.870
	ANFIS	0,60	1,30	1,50	0,00	0,00	37.640	22.772.200
1200	Hybrid PID-ANFIS	0,40	0,60	1,30	0,00	4,20	34.890	20.934.000
	Open loop	0,60	1,20	1,30	0,00	0,00	37.621	23.136.915
	PID	0,30	0,60	1,50	10,00	14,00	35.683	21.766.630
	ANFIS	0,40	1,10	1,10	0,00	0,00	34.234	20.711.570
1000	Hybrid PID-ANFIS	0,30	0,50	0,90	0,00	12,00	31.867	19.120.200

Table 5: The transient parameters of a BLDCM with load

Speed setting (r/min)	Controller structure	Turn on load		Turn off load	
		Undershoot (%)	ts (second)	*Overshoot* (%)	ts (second)
1000	Hybrid PID ANFIS	5,00	0,50	5,00	1,00
1200	Hybrid PID ANFIS	2,30	0,90	4,70	0,70
1500	Hybrid PID ANFIS	5,00	0,80	5,00	0,50
1800	Hybrid PID ANFIS	3,00	0.50	4,00	0,80
2000	Hybrid PID ANFIS	2,00	0,50	2,00	0,40

The BLDCM test with changed speed setting is meant to test the controller performance when it is given a tracking control. The first is given a speed setting of 2000 r/min, then after 3 seconds at (t=3) the speed seting is changed to 1500 r/min and finally after another 3 seconds (t=3) the speed setting is changed to 800 r/min. The speed response is shown in Figure 12.

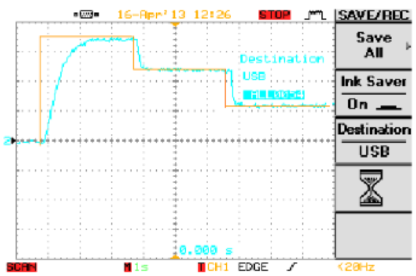


Figure 12 Speed response of BLDCM speed control when speed setting changed

6. CONCLUSION

The structure and parameter of a hybrid PID-ANFIS can improve the response performance of a BLDCM speed control. This is done by dividing the functions of PID and ANFIS controllers based on speed error domain, namely, selecting hybrid PID-ANFIS. The constribution of both the PID and the ANFIS controller is determined by the activation degree of each controller using the error relation represented by a linear curve which is limited by parameters a = 0 and b = 1. The response performance of BLDCM speed control can improved that impact to decrease of a control energy and ISE (Integral Square Error). A hybrid PID-ANFIS can be operated in a wide range speed setings.

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