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Parallel Distribution Compensation PID Based on Takagi-Sugeno Fuzzy Model Applied On DC Motor

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ABSTRACT

Most of the industrial controllers in use today utilize PID controllers. In this paper, a new Parallel Distribution Compensator PID'S controller at several operating points, under parameters variations and external disturbances for the DC motor drive system. The parameters of PID's controllers were obtained at each operating point based on harmony search optimization. An effective cost function was used to perform the offline optimization. Three optimal PID's controllers were attained for each operating point individually. The fuzzy Takagi-Sugeno (TS) can be defined as the suitable PID controller for the corresponding operating point. The simulation results provided that Parallel Distribution Takagi-Sugeno PID's controller can be updated the suitable PID controller at several operating points so, it has good dynamic response with different types of disturbances (sudden load, variable load, and speed tracking) compared to the fixed optimal PID controller. Also, it can switch the better PID controller at a suitable time.

Keywords: Takagi-Sugeno, Fuzzy, Parallel Distribution, Power System Control, PID

1 INTRODUCTION

Because of their high reliabilities, flexibilities and low costs, DC motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required. PID controllers are commonly used for motor control applications because of their simple structures and intuitionally comprehensible control algorithms. Controller parameters are generally tuned using hand-tuning or Ziegler-Nichols frequency response method. Both of these methods have successful results but long time and effort are required to obtain a satisfactory system response. Two main problems encountered in motor control are the time-varying nature of motor parameters under operating conditions and existence of noise in system loop.

Analysis and control of complex, nonlinear and/or time-varying systems is a challenging task using conventional methods because of uncertainties. Fuzzy set theory (Zadeh , 1965) which led to a new control method called *Fuzzy Control[1]* which is able to cope with system uncertainties. DC motor control is generally realized by adjusting the terminal voltage applied to the armature but other methods such as adjusting the field resistance, inserting a resistor in series with the armature circuit are also available.

Ziegler-Nichols [2] frequency response method is usually used to adjust the parameters of the PID controllers. However,

It is needed to get the system into the oscillation mode to realize the tuning procedure. The proposed approach uses both fuzzy controllers and response optimization method to obtain the approximate values of the controller parameters. Then the parameters may be slightly varied to obtain the user-defined performance of the real-time control system. Then the parameters may be slightly varied to obtain the user-defined performance of the real-time control system. Thus, it’s an actual problem to design adaptive PID controllers without getting the system into the oscillation mode. Here the mathematical model of a dc motor is used to obtain a transfer function between shaft position and applied armature voltage. This model is then built in MATLAB Simulink. Then design and tuning of proportional-integral-derivative (PID) controllers are reviewed in Simulink with the proposed design procedure.

2 DC Motor Model

In armature control of separately excited DC motors, the voltage applied to the armature of the motor is adjusted without changing the voltage applied to the field. Figure 1 shows a separately excited DC motor equivalent model.

$$v_a(\mathrm{t}) = \mathrm{R_a}\ \mathrm{i_a}(\mathrm{t}) + \mathrm{L_a}\frac{\mathrm{di_a(t)}}{\mathrm{dt}} + \mathrm{e_b} \quad (1)$$

$$\mathrm{e_b} = K_f\ i_f\ \omega(\mathrm{t}) \quad (2)$$

$$\mathrm{T(t)} = K_v\ i_f\ i_a(\mathrm{t}) = D_m\ \omega(\mathrm{t}) + J_m \frac{\mathrm{d}\omega(\mathrm{t})}{\mathrm{dt}} + T_l \quad (3)$$

$$\mathrm{T(t)} = K_t\ i_a(\mathrm{t}) \quad (4)$$

From these equations, the transfer function is derived as follows:

$$v_a(\mathrm{t}) - \mathrm{e_b} = \mathrm{R_a}\ \mathrm{i_a}(\mathrm{t}) + \mathrm{L_a}\frac{\mathrm{di_a(t)}}{\mathrm{dt}} \quad (5)$$

$$V_a\ (\mathrm{s}) - K_t\ \omega(\mathrm{s}) = (\mathrm{R_a} + \mathrm{L_a}\ \mathrm{S})\ \mathrm{I_a(s)} \quad (6)$$

$$K_t\ i_a(\mathrm{t}) - T_l = D_m\ \omega(\mathrm{t}) + J_m \frac{\mathrm{d}\omega(\mathrm{t})}{\mathrm{dt}} \quad (7)$$

$$K_t\ I_a(\mathrm{s}) - T_l = (D_m + J_m\ \mathrm{S})\ \omega(\mathrm{s}) \quad (8)$$

$$\frac{\mathrm{I_a(s)}}{V_a\ (\mathrm{s}) - \mathrm{e_b}} = \frac{1}{(\mathrm{R_a} + \mathrm{L_a}\ \mathrm{S})} \quad (9)$$

$$\frac{\omega(\mathrm{s})}{K_t\, I_a(\mathrm{s}) - T_l} = \frac{1}{(D_m + J_m\ \mathrm{S})} \quad (10)$$

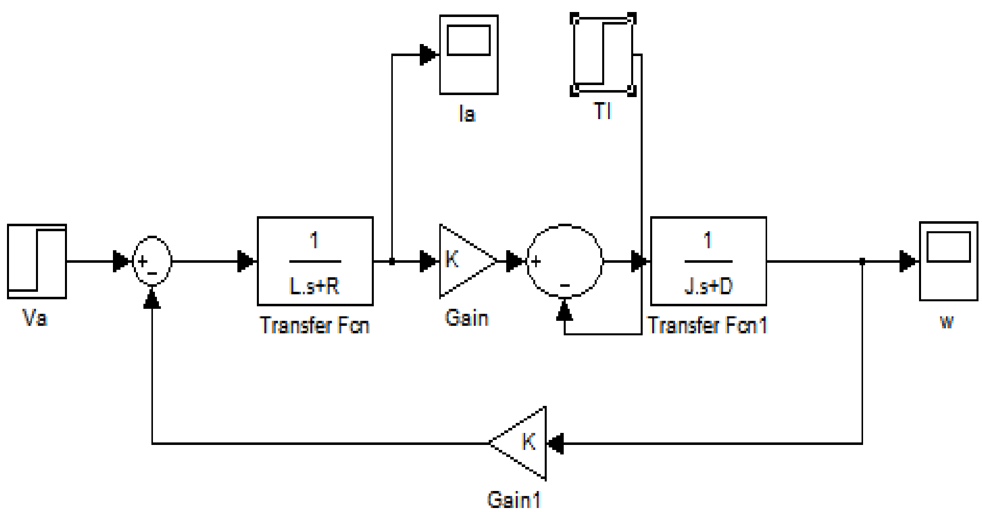

Fig. 1. DC motor Simulink block diagram.

Or from substituting the developed mechanical torque into the electrical equation:

$$I_a(s) = [\ (D_m + J_m\ S)\ \omega(s) + T_l\ ]\ /\ K_t \tag{11}$$

$$V_a\ (s) = [(R_a + L_a\ S)\ [\ (D_m + J_m\ S)\ \omega(s) + T_l\ ]\ /\ K_t\ ] + K_t\ \omega(s) \tag{12}$$

$$\text{At } T_l = 0 \tag{13}$$

$$V_a\ (s) = [(R_a + L_a\ S)\ [\ (D_m + J_m\ S)\ \omega(s)\ ]\ /\ K_t\ ] + K_t\ \omega(s) \tag{14}$$

$$\frac{\omega(s)}{V_a(s)} = \frac{K_t}{L_a\, J_m\, S^2 + (R_a\, J_m + L_a D_m)S + R_a D_m + K_t^{\ 2}} \tag{15}$$

Where:

$L_a = 0.1214$ H

$R_a = 11.4\ \Omega$

$J_m = 0.02215\ Kg.m^2$

$D_m = 0.002953$ N − m s/rad

$K_t = 1.28\ N - m - A\ (V - s - rad)$

To get the damping ratio and the natural frequency:

$$L_a\, J_m\, S^2 + (R_a\, J_m + L_a D_m)S + R_a D_m + K_t^{\ 2} \tag{16}$$

$$S^2 + \left(\frac{R_a}{L_m} + \frac{D_m}{J_m}\right)S + \frac{R_a D_m + K_t^{\ 2}}{L_a\, J_m} \tag{17}$$

$$S^2 + 2\,\zeta\omega_n\, S + \omega_n^{\ 2}$$

$$\omega_n^{\ 2} = 621.8$$

$$\omega_n = 24.9 \approx 25 \text{ Hz} \tag{18}$$

$$2\,\zeta\,\omega_n = 94.04 \tag{19}$$

$$\zeta = 1.88 \tag{20}$$

3 THE PROPOSED CONTROLLER

This section illustrates the design steps of proposed The Parallel Distributed Compensation – PID'S to improve the performance the frequency (Δf) and the controllers outputs of Egyptian load frequency control system.

3.1 The Parallel Distributed Compensation –PID 'S

The Parallel Distributed Compensation (PDC) offers a procedure to design a fuzzy controller from a given T-S fuzzy model [25]. To realize the PDC, a controlled object (nonlinear system) is first represented by a T-S fuzzy model [26]. In the PDC design, each control rule is designed from the corresponding rule of a T-S fuzzy model [27]. The constructing following fuzzy controller via the PDC is given by [28]:

Control Rule *i*:

If $Z_I(t)\ is\ M_{iI}\ ....and\ Z_P(t)\ is\ M_{iP}\ \ then\ \ u(t) = u^{(i)} = {k_p}^{(i)}.e + {k_i}^{(i)}.\int e\,dt + {k_d}^{(i)}.\Delta e$ (1)

$Where \qquad i = 1,2, \ldots r$

For building the model using a TS fuzzy model, the ranges of each parameter (pn1, pn2, pn3) according to the table (2) divides to named membership functions, as shown in Figure 2. The membership functions are assumed to be overlapped triangular shapes that have their middle vertexes positioned at the given crisp values and in a manner that assures that at any other crisp value is covered by exactly 2 membership functions.

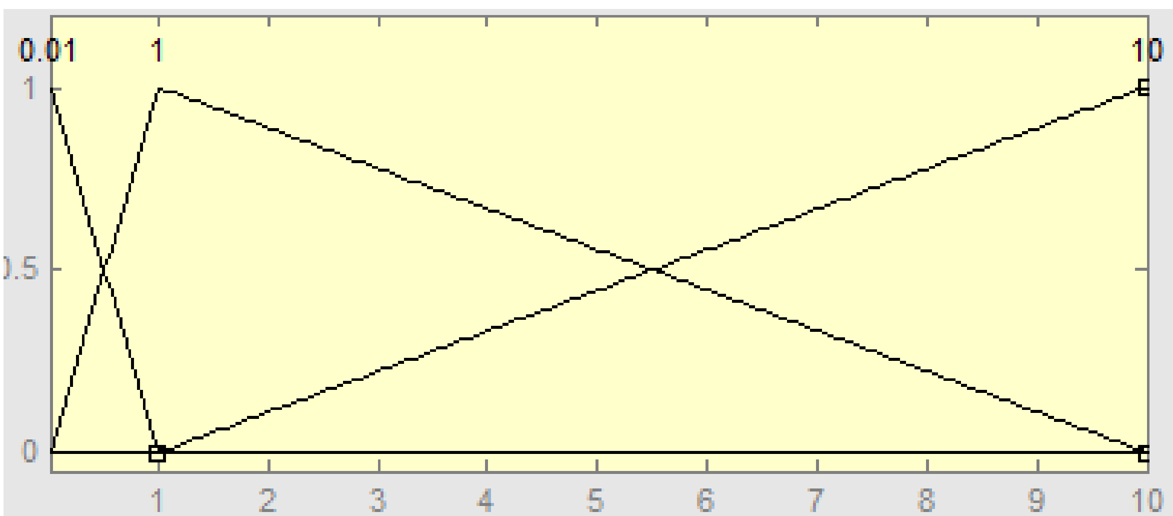

Fig. 2. Membership functions for J

3.2 The Steps of controller design:

1- Calculate the weight for each rule as follows:

$$The\ weight\ of\ i_{th}\ rule\ is\ w_i = \min\ \left(mf_1(p_{n1}), mf_2(p_{n2}), mf_3(p_{n3})\right) \qquad (21)$$

The ith weight is achieved by using triangle functions and a min block as seen in Figure 6 product block can also used instead of min):

2- Calculate the output of the controller as demonstrated in Figure 7 by implementing the following equation:

$$u = \frac{\sum_{i=1}^{r}(u^{(i)}.w_i)}{\sum_{i=1}^{r} w_i} \tag{22}$$

Let's take for example, Rule 1:

IF pn1 is about 0.2529 (the value of pn1 that corresponds to rule 1) AND pn2 is about 0.6107 (the value of pn2 that corresponds to rule 1) AND pn3 is about 0.1364 (the value of pn3 that corresponds to rule 1) then

$$u = u^{(1)} = 1.8912\, e + 0.088697 \int e\, dt + 0.9733.\Delta e \tag{23}$$

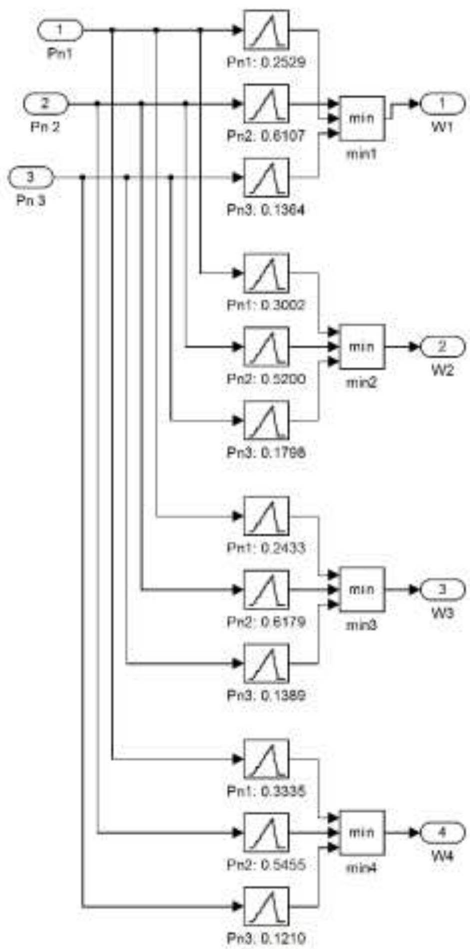

Fig. 3. Calculating the weight of one fuzzy rule

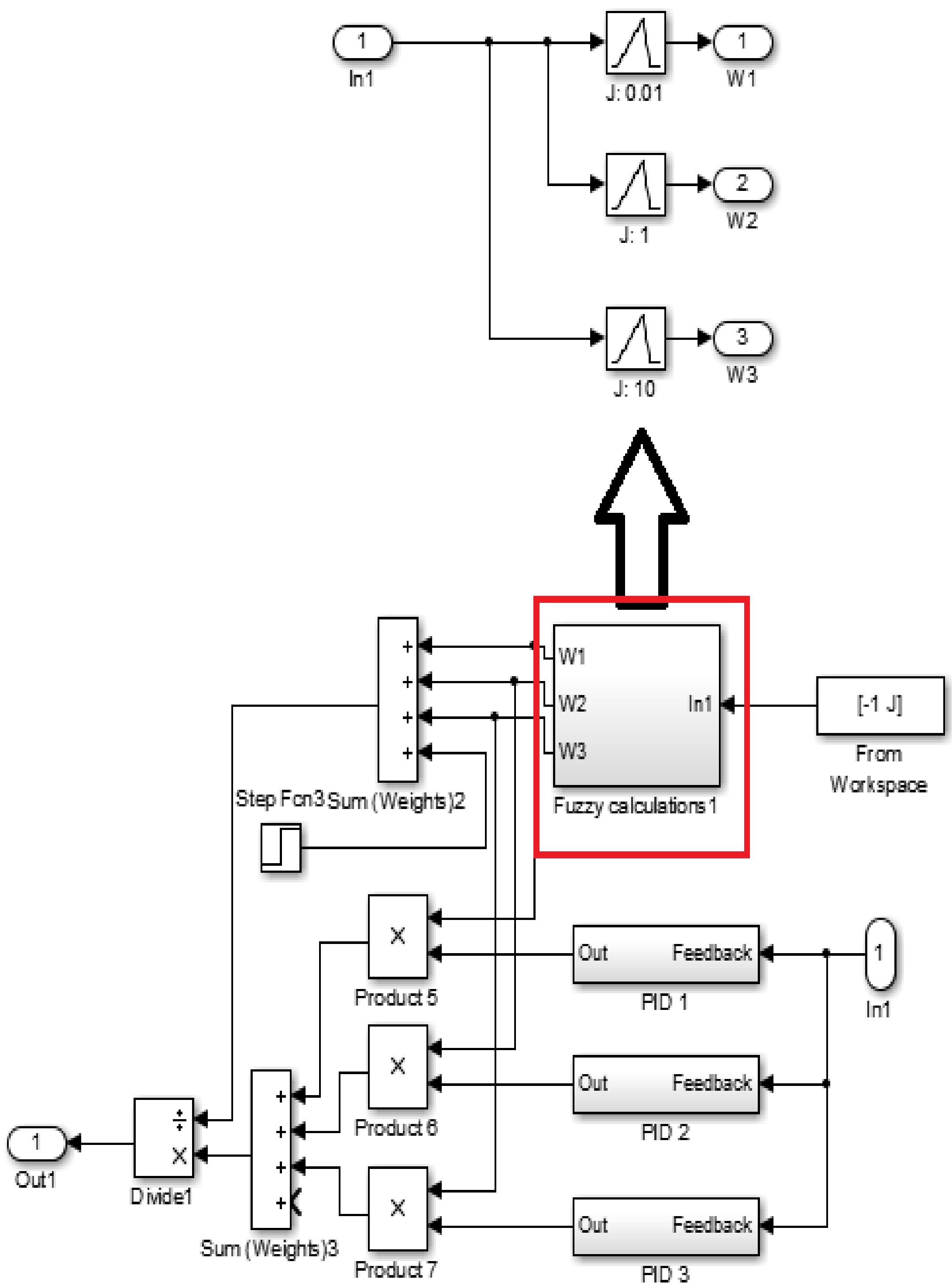

Fig. 4. The block diagram of the PDC PID controller

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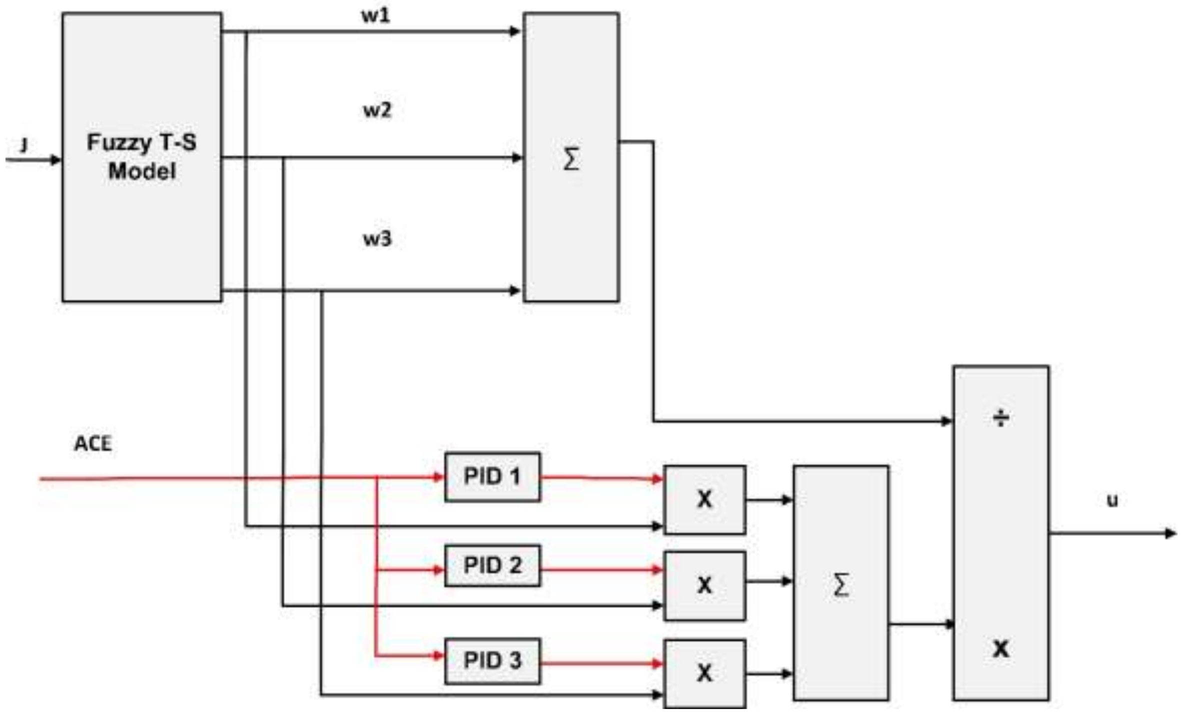


Fig. 5. Best Choice of Operating Points Using TS Fuzzy Model

3.3 Harmony Search Optimization Technique

The challenge point in the PID and FOPID controllers are selecting the appropriate parameters for a certain controlled plant. There are several methods to find the parameters of FOPID controller for example, try and error and Ziegler-Nichols method but, most of these techniques are rough roads. In this paper, the harmony search optimization technique will be used to obtain the optimal values of FOPID controller parameters according to the objective function as shown in Eq (3) [22].

$$f = \frac{1}{(1-e^{-\beta})(M_p+e_{ss})+e^{-\beta}(t_s-t_r)} \tag{24}$$

Where e_{ss} is the steady state error, M_p is the overshoot of system response, t_s is the settling time and t_r is the rise time. Also, this objective function is able to compromise the designer requirements using the weighting parameter value (β). The parameter is set larger than 0.7 to reduce over shoot and steady state error.

If this parameter is adjusting smaller than 0.7 the rise time and settling time will be reduced. Harmony search (HS) was suggested by Zong Woo Geem in 2001 [31]. It is well known that HS is a phenomenon-mimicking algorithm inspired by the improvisation process of musicians [32]. The initial population of Harmony Memory (HM) is chosen randomly. HM consists of Harmony Memory Solution (HMS) vectors.

Table 1 shows the obtained parameters of TSMFOPID controller based on harmony search optimization technique.

Table 1: TSMFOPID parameters.

TSMFOPID parameters	Kp	Kd	vd	ki	vi
Parameters values	9.5603	5.3506	0.23714	2.5926	0.922

Both of conventional toolbox of FOPID and the Takaji-Sugeno (TS) modified FOPID (TSMFOPID) have the same response through the simulation results at different operating conditions. In addition, it is provided in [21].

$$H\ M = \begin{bmatrix} K_{p\,(1,1)} & K_{i\,(1,2)} & K_{d\,(1,3)} & vd_{\,(1,4)} & vi_{\,(1,5)} \\ K_{p\,(2,1)} & K_{i\,(22)} & K_{d\,(2,3)} & vd_{\,(2,4)} & vi_{\,(2,5)} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ K_{p\,(HMS,1)} & K_{i\,(HMS,2)} & K_{d\,(HMS,3)} & vd_{\,(HMS,4)} & vi_{\,(HMS,5)} \end{bmatrix} \tag{25}$$

3.4 The Simulation Results

The simulation results are obtained using MATLAB Toolbox. Different types of disturbances are implemented to DC motor model to show the effectiveness of the proposed controllers. Many cases under disturbances with different operating points, parameter variation and parameter uncertainty are performed.

Fig. 6 shows that the performance of DC motor at normal parameters using HS-PID-1 and PDC-PID-1 controllers. The results of both controllers are identical with no overshoot. Also, the proposed controllers have the ability to track the reference speed in less time at sudden load of

30% of full load and j1=0.1 at instant 10 seconds from simulation time. Also, Fig. 7 illustrates the corresponding controller output at speed regulation and sudden load test.

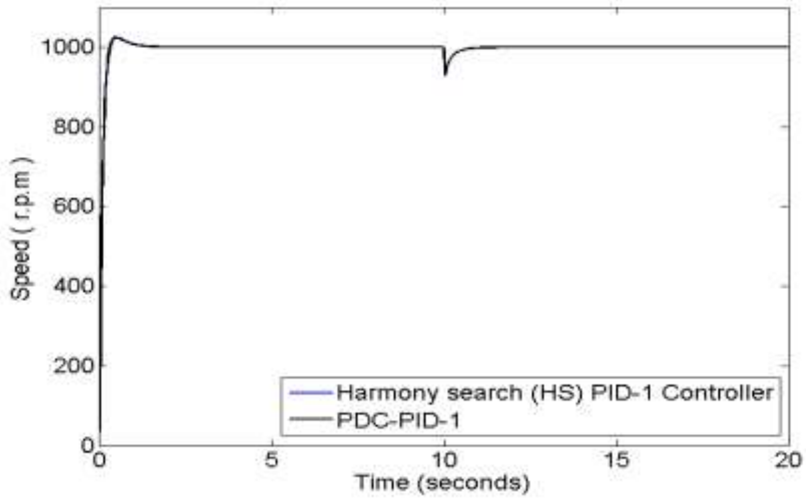


Fig. 6. The DC motor speed response at PDC-PID-1.

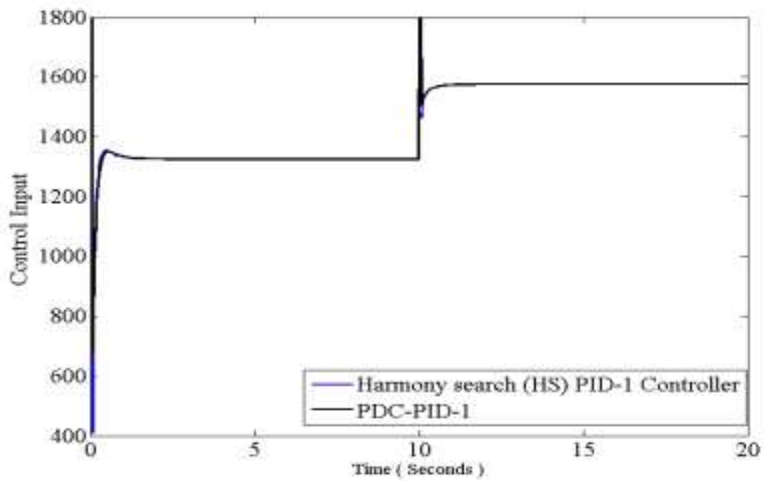


Fig. 7. The control input response at PDC-PID-1.

Fig. 8 shows that the response of DC motor at different parameters (J=0.5.) using HS-PID-1 and PDC-PID-2 controllers. The PDC-PID-1 results is fast and with acceptable overshoot. Also, the PDC-PID-1 is sensitivity to sudden disturbance in inertia and has the ability to accommodate the disturbance in less at instant 10 seconds from simulation time. Also, Fig. 9 demonstrates the corresponding controller output at speed regulation and sudden change in inertia test.

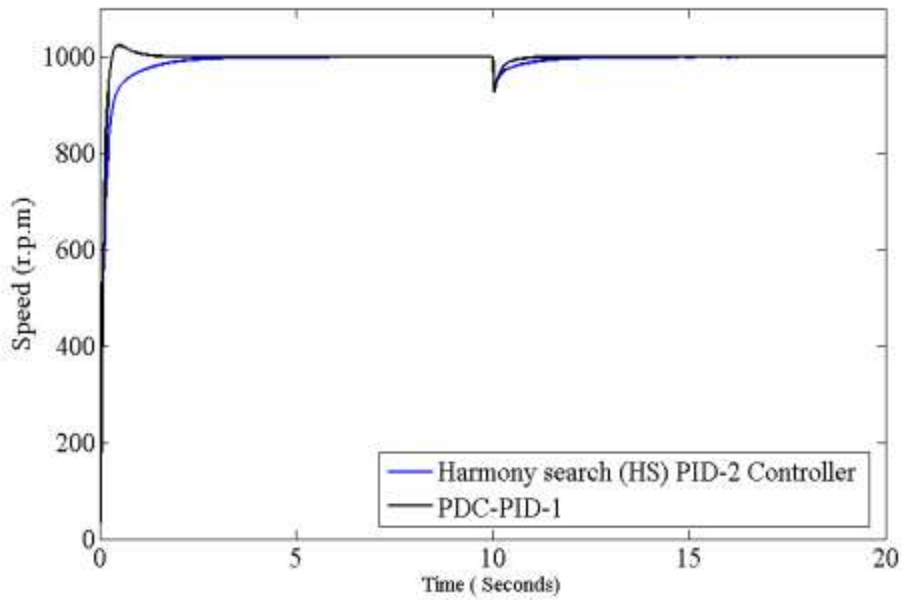


Fig. 8. The DC motor speed response at PDC-PID-1 and PID-2.

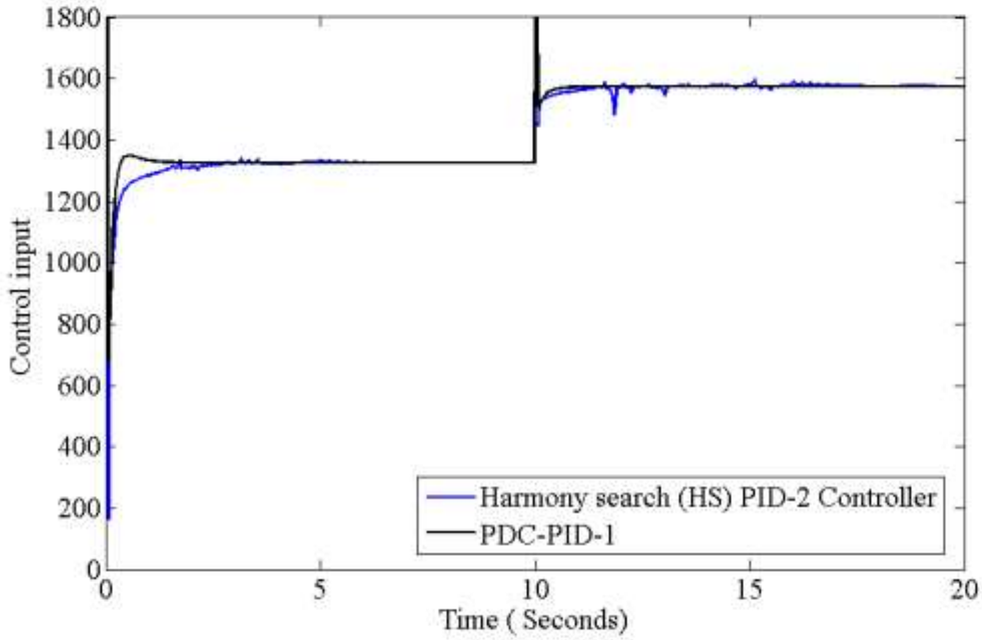


Fig. 9. The control input response at PDC-PID-1 and PID-2.

Fig. 10 appearances that the performance of DC motor at normal parameters using HS-PID-2 and PDC-PID-3 controllers. The response of PDC-PID-3 controller is faster than the HS-PID-2. Also, the PDC-PID-3 has the ability to track the reference speed in less time at sudden change in inertia (j=1) at instant 10 seconds from simulation time. Also, Fig. 11 displays the corresponding controller output at speed regulation and parameters variations test. It can be noted that the high value of controllers output at starting the simulation test.

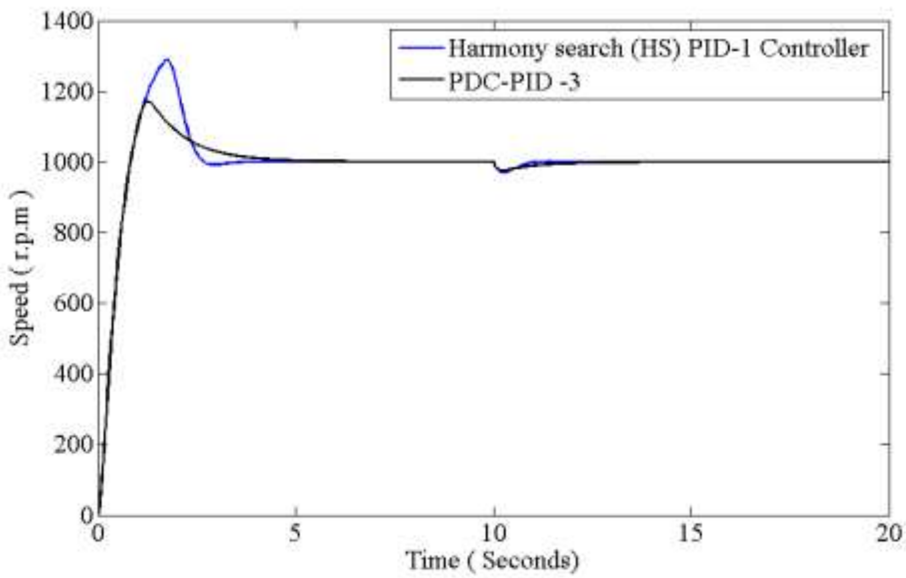


Fig. 10. The DC motor speed response at PDC-PID-3 and PID-1.

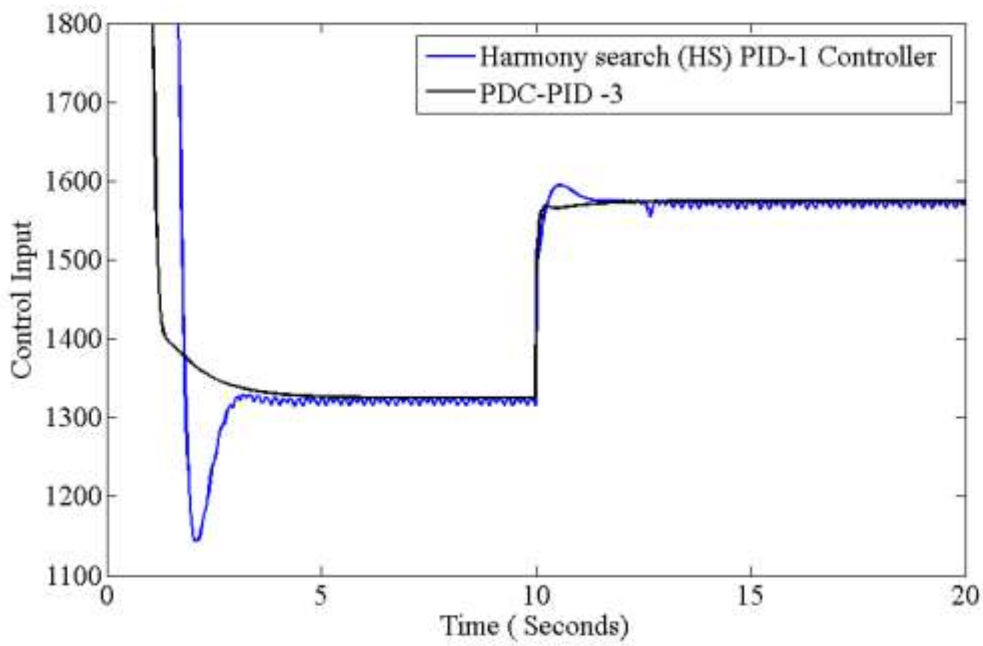


Fig. 11. The control input response at PDC-PID-3 and PID-1.

Fig. 12 shows that the performance of DC motor at normal parameters using HS-PID-3 and PDC-PID-3 controllers. The results of both controllers are identical with no overshoot. Also, the proposed controllers have the ability to track the reference speed in less time at sudden load of 70% of full load at instant 10 seconds from simulation time. Also, Fig. 13 illustrates the corresponding controller output at speed regulation and sudden load test.

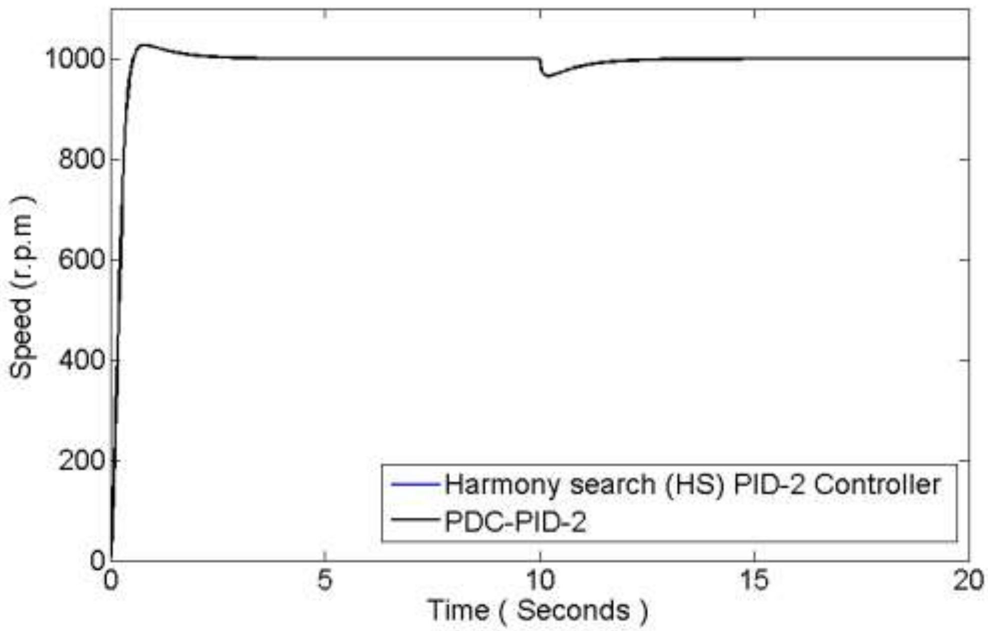


Fig. 12. The DC motor speed response at PDC-PID-2 and PID-2.

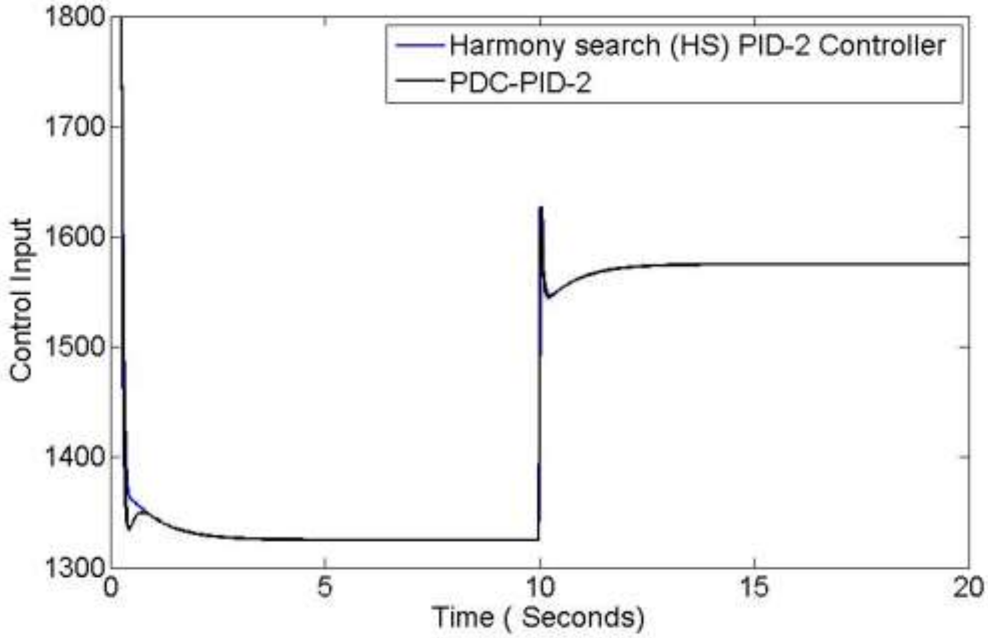
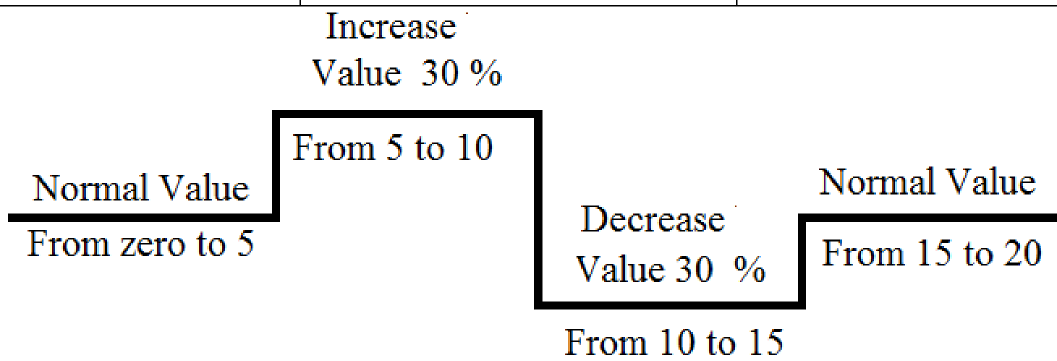


Fig. 13. The control input response at PDC-PID-2 and PID-2.

Fig. 14 demonstrates that the response of DC motor at normal parameters using HS-PID-1 and PDC-PID-1 controllers. The results of both controllers are identical with no overshoot. Also, the proposed controllers have the ability to follow the speed command rapidly at sudden load of 70% of full load at instant 10 seconds from simulation time. Also, Fig. 15 illustrates the corresponding controller output at speed regulation and sudden load test.

	Normal value	Increase 30%	decrease 30%
R	1	1.3	0.7



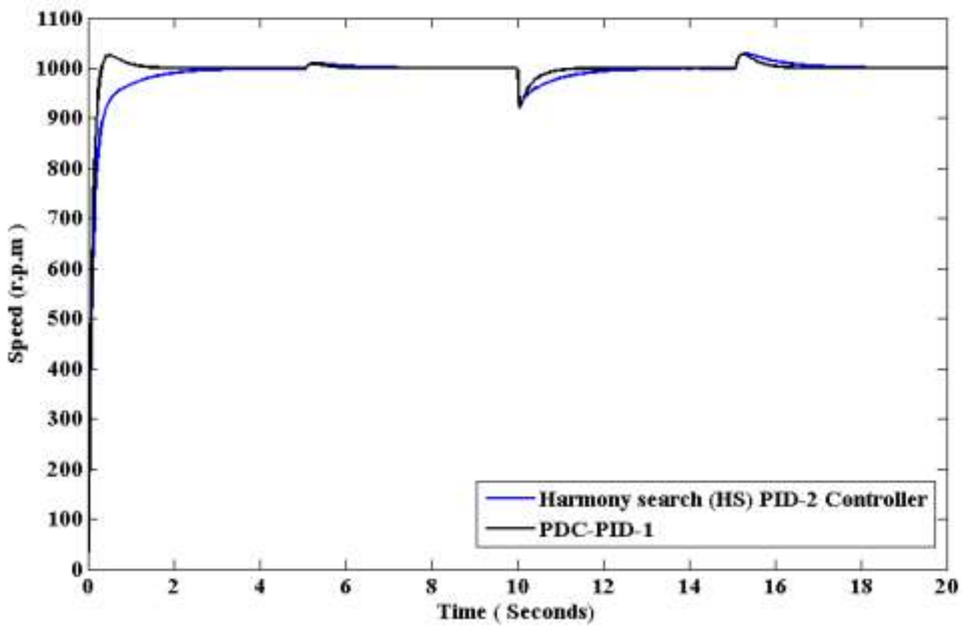


Fig. 14. The DC motor speed response at PDC-PID-1 and PID-2.

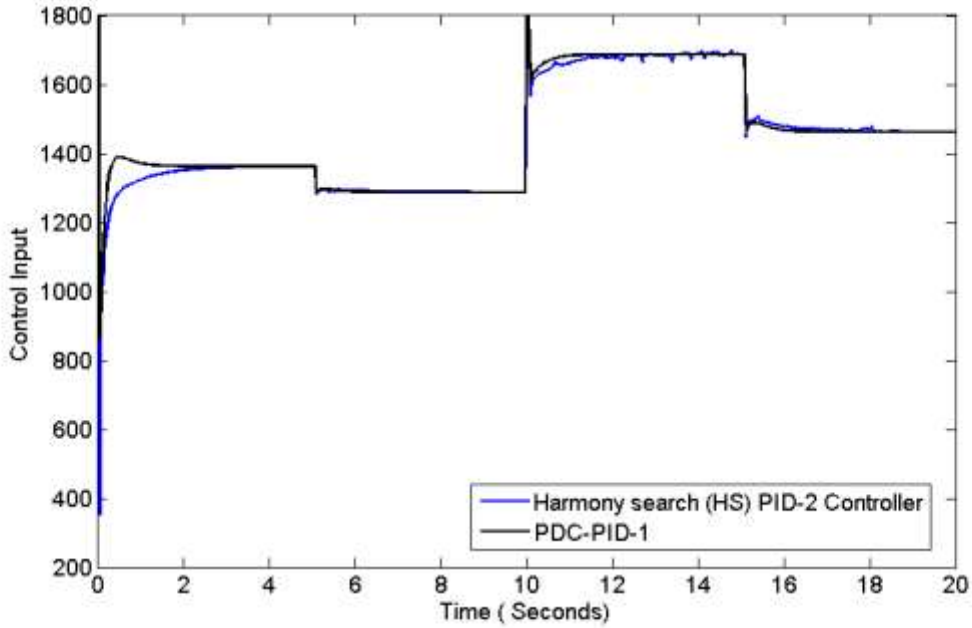


Fig. 15. The control input response at PDC-PID-1 and PID-2.

Fig. 16 displays that the response of DC motor at different operating points as in table 3 using HS-PID-2 and PDC-PID-1 controllers. The results of PDC-PID-1 controller has the fastest response (less rise time and settling time). Also, the proposed controller has the ability to follow the reference speed rapidly under parameters variations. Also, Fig. 17 shows the corresponding controller output at speed regulation and parameters variations.

	Normal value	Increase 30%	decrease 30%
R	1	1.3	0.7
	Increase Value 30 % From zero to 5	Decrease Value 30 % From 5 to 10 Increase Value 30 % From 10 to 15	Decrease Value 30 % From 15 to 20

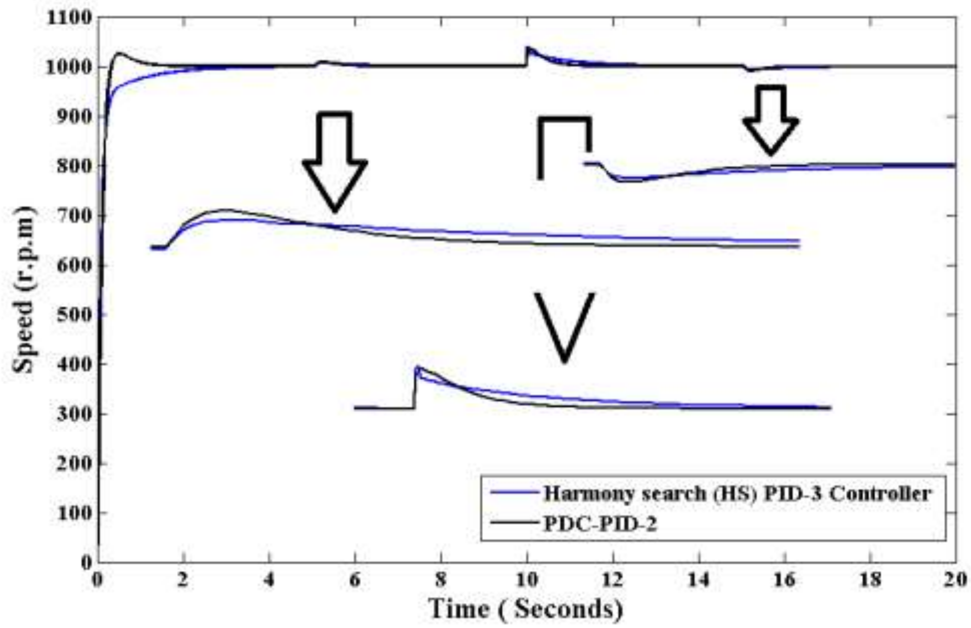


Fig. 16. The DC motor speed response at PDC-PID-2 and PID-3.

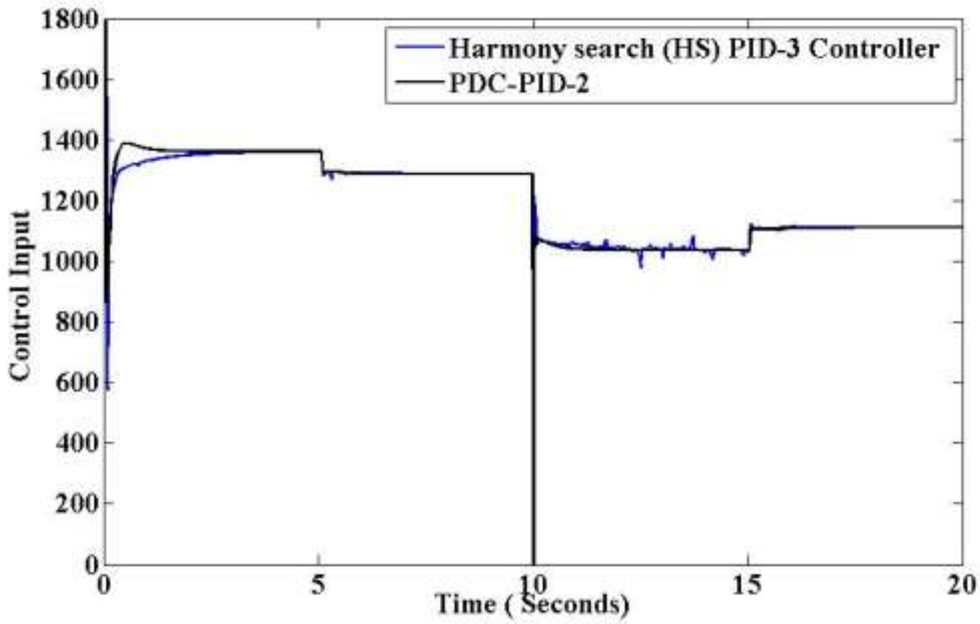


Fig. 17. The control input response at PDC-PID-2 and PID-3.

4 CONCLUSION

A new strategy for a Takagi-Sugeno Fuzzy Parallel Distribution Compensation- PID'S (TSF-PDC-PID'S) was implemented to enhance the dynamic response of DC motor. The parameters of the operating points of DC motor considers as input to a Takagi-Sugeno Fuzzy model. The proper optimal PID controller was selected using the Takagi-Sugeno Fuzzy model for a certain operating point. The ACS optimization algorithm used to optimize the parameters values of PID'S controllers at different operating points according to the selected cost function. Several types of disturbances, uncertainty and parameters variations applied on the system to ensure the validation of proposed controller. The simulation results provided that the Parallel Distribution Compensation- PID'S can select the appropriate PID controller at different operating points so, it has a good performance through different kinds of disturbances compared to fixed PID controller.

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