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COMPARISON PERFORMANCE OF DIFFERENT PID CONTROLLERS FOR DC MOTOR

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ABSTRACT: Speed control of Dc motors is an important issue also shorter settling time is desired . In this work at first a parallel PID compensator which adjusted by Ziegler – Nichols is designed but Ziegler – Nichols don't apply directly for all structures of PID controller ,drive equations to applied Ziegler - Nichols for this configuration of PID compensator . The controller design process requirements are discussed by programming . Then the comparison between the PID configurations shows that the PID controller significantly reduced the overshoot , settling time and has the best performance encountering with system uncertainties . According to the matlab programming version 7.10 results , the D*PI controller has better performance than the PID configuration .

Keywords : PID .structure .

1. INTRODUCTION

PID controllers are widely used in industrial plants because it is simple and robust. Industrial processes are subjected to variation in parameters and parameter perturbations, which when significant makes the system unstable. So the control engineers are on look for automatic tuning procedures .

From the control point of view , dc motor exhibit excellent control characteristics because of the decoupled nature of the field [(1)]. Recently, many modern control methodologies such as nonlinear control [(2)] , optimal control [(3)] , variable structure control[(4)] and adaptive control [(5)] have been extensively proposed for DC motor . However , these approaches are either complex in theorical bases or difficult to implement [(6)] . PID control with its three term functionality covering treatment to both transient and steady – states response , offers the simplest and yet most efficient solution too many real world control problems [(7)]. However , for best performance , the PID parameters used in the calculation must be tuned according to the nature of the system – while the design is generic , the parameters depend on the specific system . The PID controller calculation (algorithm) involves three separate parameters , and is accordingly sometimes called three term control : the proportional , the integral and derivative values, denoted P , I and D . The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors , and the derivative value determines the reaction based on the rate at which the error has been changing . The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element . Heuristically , these values can be interpreted in terms of time : P depends on the present error , I on the accumulation of past errors , and D is a prediction of future errors , based on current rate of change [(8)] . By tuning the three constants in the PID controller algorithm , the controller can provide control action designed for specific process requirements . The response of the controller can be described in terms of the responsiveness of the controller to an error , the degree to which the controller overshoots the set point and the degree of system oscillation . Some applications may require using only one or two modes to provide the appropriate system control . This is achieved by setting the gain of undesired control outputs to zero . A PID controller will be called a PI , PD , P or I controller in the absence of the respective control actions . PI controllers are fairly common , since derivative action is sensitive to measurement noise , where as the absence of an integral value may prevent the system from reaching its target value due to the control action .

The Ziegler – Nichols rules for tuning PID controller have been very influential (9) . The rules do , however , have severe drawbacks , they use insufficient process information and the design criterion gives closed loop systems with poor robustness (10) . Ziegler and Nichols presented two methods , a step response method and a frequency response method .

Discuss the many type of PID controller and compare this results with together to choose the optimization method to get a good result for Dc motor speed control . Firstly we take the Dc motor transfer function (11) .

$$G_p(s) = \frac{0.0147}{0.000007242\,S^2 + 0.000207S + 0.000437} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2. PID CONTROLLER

Used the following structures from PID controller :

2.1 PARALLEL PID CONTROLLER

A parallel connection of proportional , derivative , and integral element is called parallel or non interactive of PID controller. Parallel structure is shown in figure (1)

$$G_{c1}(s) = \frac{U(s)}{E(s)} = K_{p1} + \frac{K_{i1}}{s} + K_{d1}s$$

$$G_{c1}(s) = K_{d1}\,\frac{\left(s + \frac{1}{2}\frac{K_{p1}}{K_{d1}} + \frac{1}{2}\sqrt{\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\frac{K_{i1}}{K_{d1}}}\right)\left(s + \frac{1}{2}\frac{K_{p1}}{K_{d1}} - \frac{1}{2}\sqrt{\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\frac{K_{i1}}{K_{d1}}}\right)}{s} \quad \ldots\ldots\ldots (2)$$

2.2 PI-D CONTROLLER

Because of possible discontinuity (step change) in reference signal that are transferred into error signal and result in impulse traveling through derivative channel and thus cause large control signals u , it is more suitable in practical implementation to use "PI-D" . It is even more suitable controller structure if there exist sensors that give that information , such tachometers in electrochemical servo systems or " rate gyro" in mobile objects control . If PI-D structure (fig.2) is used , discontinuity in r(t) will be still transferred through proportional into control signal u , but it will not have so strong effect as it was amplified by derivative element .

$$G_{c2}(s) = \frac{U(s)}{E(s)} = \left(K_{p2} + \frac{K_{i2}}{s}\right)$$

$$= K_{p2}\,\frac{\left(s + \frac{K_{i2}}{K_{p2}}\right)}{s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

2.3 SERIAL (D*PI) CONTROLLER

This structure is very often in process industry. I channel uses both the error signal e(t) and derivative of the error signal $\frac{de(t)}{dt}$. It is realized as serial connection of PD and PI controller. as shown in figure (3)

$$G_{c3}(s) = \frac{U(s)}{E(s)} = (1 + K_{d3}s)\left(K_{p3} + \frac{K_{i3}}{s}\right)$$
$$= (1 + K_{d3}s)\left(\frac{K_{p3}s + K_{i3}}{s}\right)$$
$$= K_{d3}K_{p3}\ \frac{(s+\frac{1}{K_{d3}})(s+\frac{K_{i3}}{K_{p3}})}{s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

It is found new type from PID controller and called serial structure (I*PD) controller , this type is shown in figure (4) .

$$G_{c4}(s) = \frac{U(s)}{E(s)} = \left(1 + \frac{K_{i4}}{s}\right)(K_{p4} + K_{d4}s)$$
$$= \left(\frac{s+K_{i4}}{s}\right) K_{d4}\ \left(s + \frac{K_{p4}}{K_{d4}}\right)$$
$$= K_{d4}\ \frac{(s+K_{i4})(s+\frac{K_{p4}}{K_{d4}})}{s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

3. ZIEGLER – NICHOLS TUNING

In 1942 Ziegler and Nichols , both employees of Taylor Instruments , described simple mathematical procedures , the first and second methods respectively , for tuning PID controllers . These procedures are now accepted as standard in control systems practice . Both techniques make a priori assumptions on the system model , but do not require that these models be specifically known . Ziegler-Nichols formulae for specifying the controllers are based on plant step responses.

The first method is applied to plants with step responses of the form displayed in figure (5). This type of response is typical of a first order system with transportation delay , such as that induced by fluid flow from a tank along a pipe line . It is also typical of a plant made up of a series of first order systems. The response is characterized by two parameters , L the delay time and T the time constant. These are found by drawing a tangent to the step response at its point of inflection and noting its intersections with the time axis and the steady state value . The plant mode l is therefore

$$G(s) = \frac{K\ e^{-sL}}{TS+1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Ziegler and Nichols derived the following control parameters based on this model where

$$T_i = K_i/K_p$$

and

$$T_d = K_d/K_p$$

Transfer function of PID controller tuned using the first method

$$G_c(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right)$$
$$= 1.2\frac{T}{L}\left(1 + \frac{1}{2L\ s} + 0.5\ LS\right)$$
$$= 0.6T\frac{\left(s+\frac{1}{L}\right)^2}{s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

It should be noted that the response curve of figure (5) is also typical of over damped second order systems.

Applied Ziegler - Nichols first method on the parallel PID controller to choose a suitable parameter of PID controller , and from table (1) get T = 0.55 & L = 0.05 . this values of $K_{p1} = 13.2,\ K_{i1} = 132\ \&\ K_{d1} = 0.33$ .To apply this method on the serial structure from PID controller , we found the relationship between PID controller and D*PI , I*PD controllers . This relationship illustrate for the following steps :

i – By comparison equations (2) and (4) we get

$$K_{d1} = K_{d3}\ K_{p3} \quad \cdots\cdots (8)$$

$$\frac{1}{2}\frac{K_{p1}}{K_{d1}} + \frac{1}{2}\sqrt{\left(\frac{K_{p1}}{K_{d1}}\right)^2 - 4\frac{K_{i1}}{K_{d1}}} = \frac{1}{K_{d3}} \quad \cdots\cdots (9)$$

$$\frac{1}{2}\frac{K_{p1}}{K_{d1}} - \frac{1}{2}\sqrt{\left(\frac{K_{p1}}{K_{d1}}\right)^2 - 4\frac{K_{i1}}{K_{d1}}} = \frac{K_{i3}}{K_{p3}} \quad \cdots\cdots (10)$$

By addition

$$\frac{K_{p1}}{K_{d1}} = \frac{1}{K_{d3}} + \frac{K_{i3}}{K_{p3}}$$

$$\frac{K_{p1}}{K_{d1}} = \frac{K_{p3} + K_{i3} K_{d3}}{K_{p3} K_{d3}}$$

$$\frac{K_{p1}}{K_{p3} K_{d3}} = \frac{K_{p3} + K_{i3} K_{d3}}{K_{p3} K_{d3}}$$

$$K_{p1} = K_{p3} + K_{i3} K_{d3} \quad \cdots\cdots (11)$$

$$K_{p3} = K_{p1} - K_{i3} K_{d3} \quad \cdots\cdots (12)$$

$$\frac{1}{2}\frac{K_{p1}}{K_{d1}} + \frac{1}{2}\sqrt{\left(\frac{K_{p1}}{K_{d1}}\right)^2 - 4\frac{K_{i1}}{K_{d1}}} = \frac{1}{K_{d3}}$$

$$\frac{1}{2}\sqrt{\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\ \frac{K_{i1}}{K_{d1}}} = \frac{1}{K_{d3}} - \frac{1}{2}\frac{K_{p1}}{K_{d1}}$$

$$\frac{1}{2}\sqrt{\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\ \frac{K_{i1}}{K_{d1}}} = \frac{2K_{d1} - K_{p1} K_{d3}}{2K_{d1} K_{d3}}$$

$$\left[\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\ \frac{K_{i1}}{K_{d1}}\right]^{\frac{1}{2}} = \frac{2K_{d1} - K_{p1} K_{d3}}{K_{d1} K_{d3}} \quad \cdots\cdots (13)$$

after we substituting equation (11) in equation (13) we get

$$\left[\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\ \frac{K_{i1}}{K_{d1}}\right]^{\frac{1}{2}} = \frac{2K_{d3} K_{p3} - K_{d3}(K_{p3} + K_{i3} K_{d3})}{K_{d3}^{\ 2} K_{p3}}$$

$$\left[\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\ \frac{K_{i1}}{K_{d1}}\right]^{\frac{1}{2}} = \frac{K_{d3} K_{p3} - K_{i3} K_{d3}^{\ 2}}{K_{d3}^{\ 2} K_{p3}}$$

$$\left[\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\ \frac{K_{i1}}{K_{d1}}\right]^{\frac{1}{2}} = \frac{K_{p3} - K_{i3}\ K_{d3}}{K_{d3}\ K_{p3}}$$

$$\left(\frac{K_{p1}}{Kd1}\right)^2 - 4\ \frac{K_{i1}}{K_{d1}} = \frac{(K_{p3} - K_{i3}\ K_{d3})^2}{K_{d3}^{\ 2}\ K_{p3}^{\ 2}}$$

$$\frac{(K_{p3} - K_{i3}\ K_{d3})^2}{K_{d3}^{\ 2}\ K_{p3}^{\ 2}} - \frac{(K_{p3} - K_{i3}\ K_{d3})^2}{K_{d3}^{\ 2}\ K_{p3}^{\ 2}} = 4\ \frac{K_{i1}}{K_{d1}}$$

$$\frac{(K_{p3}^{\ 2} + 2K_{p3}\ K_{i3} K_{d3} + K_{d3}^{\ 2} K_{i3}^{\ 2})(K_{p3}^{\ 2} - 2K_{p3}\ K_{i3} K_{d3} + K_{d3}^{\ 2} K_{i3}^{\ 2})}{K_{d3}^{\ 2}\ K_{p3}^{\ 2}} = 4\ \frac{K_{i1}}{K_{d1}}$$

$$\frac{4K_{p3}K_{i3}K_{d3}}{K_{d3}{}^{2}K_{p3}{}^{2}} = 4\frac{K_{i1}}{K_{d3}\ K_{p3}}$$

$$K_{i3} = K_{i1} \quad \cdots\cdots (14)$$

$$K_{d3} = \frac{1}{\frac{1}{2}\frac{K_{p1}}{K_{d1}} + \frac{1}{2}\sqrt{\left(\frac{K_{p1}}{Kd1}\right)^{2} - 4\frac{K_{i1}}{K_{d1}}}} \quad \cdots\cdots (15)$$

ii – By comparison equations (2) and (5) we get

$$K_{d1} = K_{d4} \quad \cdots\cdots (16)$$

$$\frac{1}{2}\frac{K_{p1}}{K_{d1}} + \frac{1}{2}\sqrt{\left(\frac{K_{p1}}{Kd1}\right)^{2} - 4\frac{K_{i1}}{K_{d1}}} = K_{i4} \quad \cdots\cdots (17)$$

$$\frac{1}{2}\frac{K_{p1}}{K_{d1}} - \frac{1}{2}\sqrt{\left(\frac{K_{p1}}{Kd1}\right)^{2} - 4\frac{K_{i1}}{K_{d1}}} = \frac{K_{p4}}{K_{d4}} \quad \cdots\cdots (18)$$

By addition

$$\frac{K_{p1}}{K_{d1}} = K_{i4} + \frac{K_{p4}}{K_{d4}}$$

$$\frac{K_{p1}}{K_{d4}} = \frac{K_{p4} + K_{i4}K_{d4}}{K_{d4}}$$

$$K_{p4} = K_{p1} - K_{i4}\,K_{d4} \quad \cdots\cdots (19)$$

4 . RESULTS AND DISCUSSION

After substituting the values of $K_{p1} = 13.2,\ K_{i1} = 132\ \&\ K_{d1} = 0.33$ in equations (12), (14) , (15) , (16) , (17) & (19) we get the following results

$K_{p3} = 6.6$, $K_{i3} = 132$, $K_{d3} = 0.05$

$K_{p4} = 6.6$, $K_{i4} = 20$ $K_{d4} = 0.33$

substituting the above results in figures (1) , (3) & (4) and by using Matlab version 7.10 , we get the same output ; this illustrates as shown in figure (6) and around this values we get the values of K_p,K_i & K_d to minimize the maximum peak overshoot and settling time , this results are illustrated in table (2) . From table (2) we get the same results for many PID configuration but different values of K_p,K_i & K_d , these values are lower than any values of configurations of PID when we use D*PI configuration . therefore D*PI configuration is better than another configuration of PID controller. We made tuning on the type PI-D from PID controller and we get the results are illustrate in table (3) . From table (3) we get the best result when the values $K_{p2} = 5, K_{i2} = 1\ \&\ K_{d2} = 0.1$ and we get MP = 0% & ts = 0.0747 sec .From table (2) the best output response when the values $K_{p3} = 1.973935317$,$K_{i3} = 1$ & $K_{d3} = 0.026064683$ and we get MP = 2% & ts=0.0261 sec , this values of MP & ts are suitable for this system because of the MP don’t increase the tolerance and the ts is suitable too this illustrated in figure (7).

5. CONCLUSIONS

The Dc motor speed control needs the accuracy , because the overshooting state and steady – state error affect motor operation and response . The design and implementation of a dc motor speed system using many types from PID controller have been presented in this project . We find the parameters for the PID controller by Ziegler – Nichols at first , and by try and error we find these parameters for many types from PID controller . Ziegler – Nichols method applied only in parallel PID controller , we make the mathematical algorithm which can be used in

Ziegler – Nichols method for all type of PID . By comparison these types , we find D*PI controller is the best type from PID for lower values from gains . According to the results the PID controller has the better performance encountering with noise and disturbance and parameter variation .

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LIST OF SYMBOLS

T	Time
E	Error
L	Delay time
T	Delay constant
y(t)	Dc motor velocity (step response)
u(t)	Dc motor input
r(t)	Reference input (step function)
e(t)	Error between Dc motor velocity and reference input
Mp	Maximum peak overshoot
Ts	Settling time

LIST OF ABBREVIATIONS

P	Proportional
I	Integral
D	Derivative
PID	Proportional – Integral – Derivative
PD	Proportional – Derivative
PI	Proportional – Integral
K_p	Proportional gain
K_i	Integral gain
K_d	Derivative gain
T_d	Derivative time
T_i	Integral time
D*PI	Serial controller

Table (1): Ziegler - Nichols Recipe – First Method.

Type of controller	K_p	Ti	Td
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	$2L$	$0.5L$

Table (2): MP & settling time for different structure of PID.

PID (K_{p1}, K_{i1}, K_{d1})	**D*PI** (K_{p3}, K_{i3}, K_{d3})	**I*PD** (K_{p4}, K_{i4}, K_{d4})	**Mp(%)**	**Settling time(sec)**
0.496639 1.091 0.00599889	0.483091272 1.091 0.012417715	0.013547727 80.53011013 0.00599889	9.48	0.176
2 1 0.04	1.9797959 1 0.0202041	0.0202041 49.4949 0.04	5.18	0.0677
2 1 0.05	1.974679434 1 0.025320565	0.025320565 39.49358869 0.05	2.32	0.051
2 1 0.0512	1.974063653 1 0.025936347	0.025936347 38.55593072 0.0512	2.05	0.0461
2 1 0.0513	1.97401232 1 0.025987679	0.029835657 38.47977232 0.0513	2.03	0.0454
2 1 0.0514	1.973960985 1 0.026039015	0.026039015 38.403901021 0.0514	2.01	0.0443
2 1 0.05145	1.973935317 1 0.026064683	0.026064683 38.36608972 0.05145	2	0.0261
2 1 0.09	1.953939201 1 0.04606798	0.046060798 21.71043557 0.09	0	0.0559

Table (3): MP & settling time for PI-D controller.

PI-D (K_{p2}, K_{i2}, K_{d2})	Mp(%)	Settling time (sec)
2 , 1 , 0.025	7.97	0.0911
5, 1 , 0.05	6.77	0.0583
5 , 1 , 0.06	2.71	0.0551
5 , 1 , 0.07	0.44	0.0416
5 , 1 , 0.1	0	0.0747

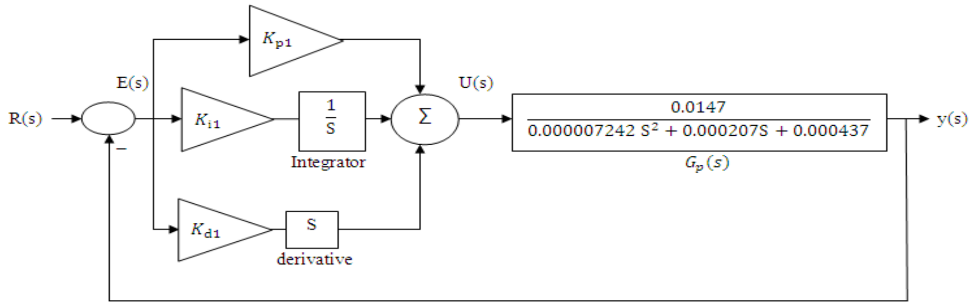

Fig.(1): Parallel PID controller.

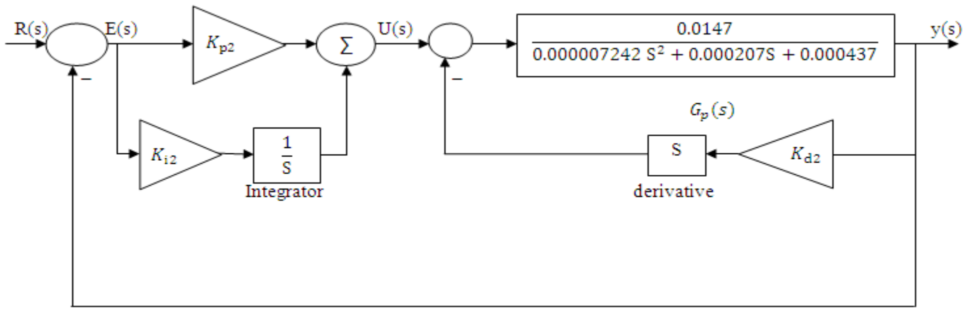

Fig.(2): PI-D controller.

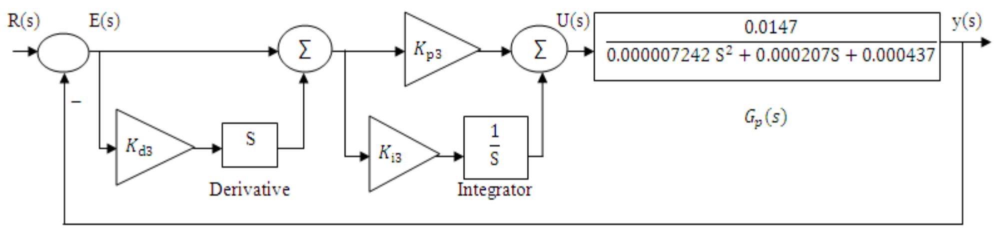

Fig.(3): Serial (D*PI) controller.

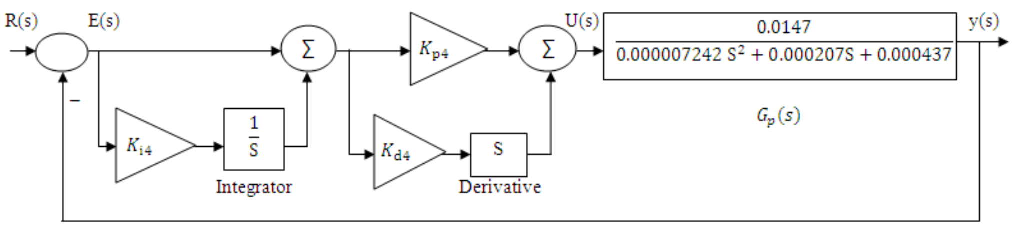

Fig.(4): Serial (I*PD)controller.

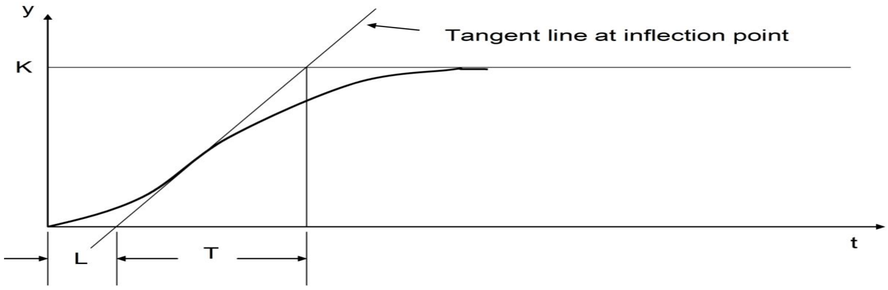

Fig.(5): Response Curve for Ziegler-Nichols First Method.

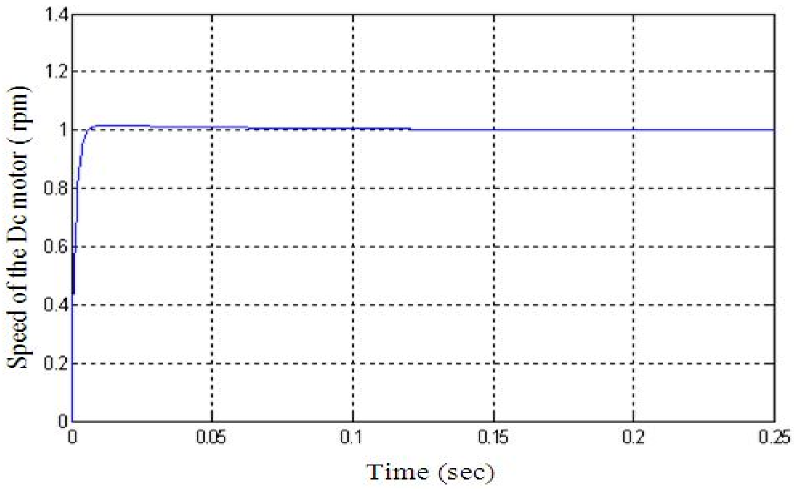

Fig.(6): Output response with PID controller.

$$K_{p1} = 13.2, K_{i1} = 132 \ \& \ K_{d1} = 0.33$$

$$K_{p3} = 6.6, K_{i3} = 132 \ \& \ K_{d3} = 0.05$$

$$K_{p4} = 6.6, K_{i4} = 20 \ \& \ K_{d4} = 0.33$$

Mp(%) = 1.54 & ts= 0.00504 sec

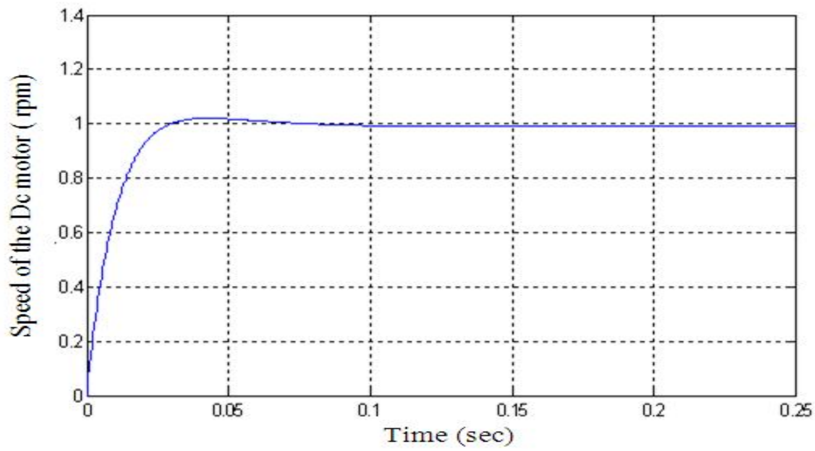

Fig.(7): Output response with PID controller

$$K_{p1} = 2, K_{i1} = 1 \ \& \ K_{d1} = 0.05145$$

$$K_{p3} = 1.973935317, K_{i3} = 1 \ \& \ K_{d3} = 0.026064683$$

$$K_{p4} = 0.026064683, K_{i4} = 38.36608972 \ \& \ K_{d4} = 0.05145$$

Mp(%) = 2 & ts= 0.0261 sec

أداءمقارنةِ لأجهزةِ سيطرة PID المختلفة لمحرك ذو تغذية مستمرة

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الخلاصة

السيطرة على سرعة المحركات ذات التغذية المستمرة مهمة بالإضافة إلى ذلك منتشرة لتصميم أقصر زمن استقرار للمنظومة , في هذا البحث تم ضبط تعديل PID وتصميمه بواسطة طرق (Ziegler - Nichols) بعد ذلك صممنا تعديل النظام بواسطة عدة تراكيب من PID ولكن (Ziegler – Nichols) لا يمكن تطبيقها على الأنواع الجديدة مباشرة ، لذلك تم اشتقاق معادلات تفاضلية لغرض تطبيق (Ziegler – Nichols) مباشرة على جميع التراكيب في هذا البحث ، من خلال النتائج وجدنا أن D*PI هو أفضل تركيب من تراكيب الـ PID وذلك لأنه يستخدم اقل قيم ويعطينا نفس النتائج ، البرمجة بواسطة (Matlab V . 7.10) ملائمة لإظهار هذه النتائج .

الكلمات الدالة : جهاز السيطرة PID ، تركيب.