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On Line Tuning of PID Parameters using Fuzzy Logic for DC Motor Speed Control

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Abstract —
Direct current motors have been used in many practical applications for their good characteristics i.e. variable speed and high staring torque. Most of the applications need variable speed drive with precise speed adjustment at certain values. Form this point of view, robust speed control system is needed. In this research proportional-integral- derivative (PID) control scheme is used for DC motor speed control. PID controller has a simple structure and exhibit robust performance over a wide range of operating conditions. The PID controller gathers the advantages of both proportional integral (PI) and proportional derivative (PD) controllers. The major difficulty with the use of PID controller is the tuning of it is gain parameters i.e. the proportional gain (K_P), the integrated gain (K_I), and the differential gain (K_D). The values of these parameters affect the characteristics of the time response i.e. the rising time (Tr), the settling time (Ts), the peak overshoot (P.O.S) and the steady state error (ess). In the present work PID controller is tuned using two methods :.
The First: The conventional method (trial and error) the drawbacks of this tuning method is the long time needed for tuning and the lake of ability to adapt any external influences and disturbances.
The second: The intelligent method (Fuzzy Logic) in this method fuzzy logic is used for tuning the gain parameters of the PID controller and to solve the tuning problems in the conventional method. This method allows instantaneous and real time tuning of the controller parameter.

Index Terms- *PID controller, Fuzzy tuning PID, DC motor.*

I. Introduction

The electric motors are used in a wide range of mechanical energy source driving wheel industrial productivity, there are different types of electric motors including DC motors with some advantages, including access to a wide range of speed higher or lower speed and with high starting Torque makes it suitable for many applications, as well as above the speed control systems featuring simple and low cost compared with AC motors and other types [1]. One of the most important applications that use DC motors for robots, automobiles, electric trains, and all applications requiring variable speed high installation accuracy [2], hence the need to build a robust control systems work.
the proportional integral differential controller (PID): the controller is durability and simple structure and combines the advantages of both controlling the proportional integral (PI) and controlling the proportional differential (PD) and this leads to improved transient and steady state response situation by reducing the steady state error to zero (ess = 0). Use this controller in industrial applications is largely due to the high degree of competence, Controller parameters are generally tuned using hand-tuning or Ziegler-Nichols are conventional method, Both of these methods have long time for tuning parameters and the controller does not possess the flexibility to adapt if the system to external influences (e.g. due to plant parameter variations or operating condition changed) [3].
Because above problem of conventional tuning methods, there is a significant need to develop methods for the automatic tuning of PID controllers. Emerging intelligent techniques have been developed and extensively used to improve conventional tuning methods for PID controller because these techniques do not require a mathematical model [4]. One of intelligent technique, Fuzzy logic control (FLC) is one of the most successful applications of fuzzy set theory, introduced by L.A Zadeh in 1973 and applied (Mamdani 1974) in an attempt to control system that are structurally difficult to model. Since then, FLC has been an extremely active and fruitful research area with many industrial applications reported [5].

II. PID Controller

The PID controller is used to improve the dynamic response and reduce the steady state error and used in industrial control applications due to simple structures [6]. The Figure 1 explain the block diagram of PID Controller.

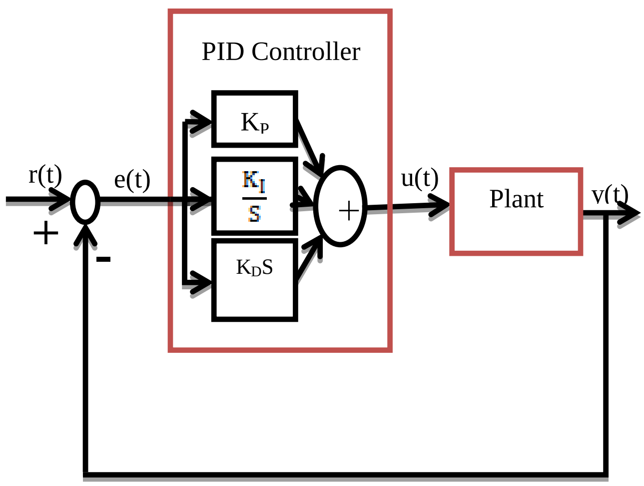

Fig.1 the block diagram of PID Controller

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- *Ibrahim Ismael: was born in mosul in 1989. He got the B.Sc. and M.Sc. from the mosul University in 2011, 2014 respectively, in Electrical Engineering. mosul University, Department of Electrical Engineering.*

From the fig.1 we can the write equation of PID Controller where:

$$e(t) = r(t) - y(t) \qquad \dots\dots\dots\dots (1)$$

$$u(t) = K_p\, e(t) + K_I \int e(t)\, dt + K_D \frac{de(t)}{dt} \qquad \dots\dots\dots\dots (2)$$

Where K_P: Proportional gain, K_I: Integral gain, K_D:Derivative gain.

The variable e(t) represents the tracking error which is the difference between the desired input value r(t) and the actual output y(t). This error signal will be sent to the PID controller and both the derivative and the integral of this error signal are computed by the controller [7].

Table (1) Effects of Independent P, I, and D Tuning [8]

Increase Parameter	Rise Time (tr)	Overshoot (Mp) %	Settling Time (ts)	Steady State error (ess)
K_P	decrease	Increase	Small Increase	decrease
K_I	Small decrease	Increase	Increase	Large decrease
K_D	Small decrease	decrease	decrease	No effect

III. Tuning Methods of PID Controller

In this Paper used Two method of tuning PID Controller:

A. conventional Method (Trial and Error):

PID controllers are usually tuned using trial and error.

procedure of the Tuning method [9]:

1. Remove the Integral and Derivative gain by setting $K_I = K_D$=0.
2. Tune K_P such that it gives the desired response except the final offset value from the set point.
3. Increase K_P slightly and adjust K_D to dampen the overshoot.
4. Tune K_I such that final offset is removed.
5. Repeat steps from no.3 until is as large as possible.

The disadvantage of this method is that it should take a long time to find the optimal values.

B. Intelligent method (Fuzzy Tuning PID):

Fuzzy tuning PID contain from two inputs-three outputs self-tuning of a PID controller. The controller design used the error (e) and change of error (Δe) as inputs, and the gains (K_{PF}, K_{IF}, K_{DF}) as outputs. The FLC is adding to the conventional PID controller to adjust the parameters of the PID controller on-line according to the change of the signals error and change of the error [10].

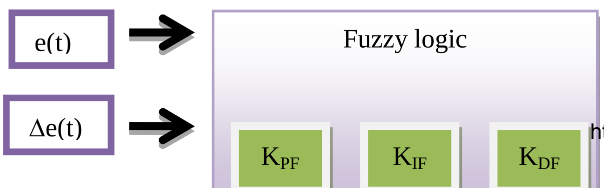


Fig. 2 the block diagram of Fuzzy Tuning PID Controller

Now the control action of the PID controller after self-tuning can be describing as:

$$u(t) = K_{PN}\, e(t) + K_{IN} \int e(t)\, dt + K_{DN} \frac{de(t)}{dt} \qquad \dots\dots\dots\dots (3)$$

Where (K_{PN}, K_{IN} and K_{DN})are the new gains of PID Controller.

$$K_{PN} = K_{PF} \times K_P \qquad \dots\dots\dots\dots (4)$$

$$K_{IN} = K_{IF} \times K_I \qquad \dots\dots\dots\dots (5)$$

$$K_{DN} = K_{DF} \times K_D \qquad \dots\dots\dots\dots (6)$$

Where (K_{PF}, K_{IF} and K_{DF}) are the gains outputs of fuzzy control, that are varying online with the output of the system under control, and (K_P, K_I and K_D) are the initial value PID Parameter found in the conventional Tuning method.

Fuzzy logic is a method of rule-based decision making used for expert systems and process control that emulates the rule-of-thumb thought process used by human beings. The basis of fuzzy logic is fuzzy set theory which was developed by Lotfi Zadeh in the1960s [11].

In this paper the member ship function of the (e, Δe, K_{PF}, K_{IF}, and K_{IF}).

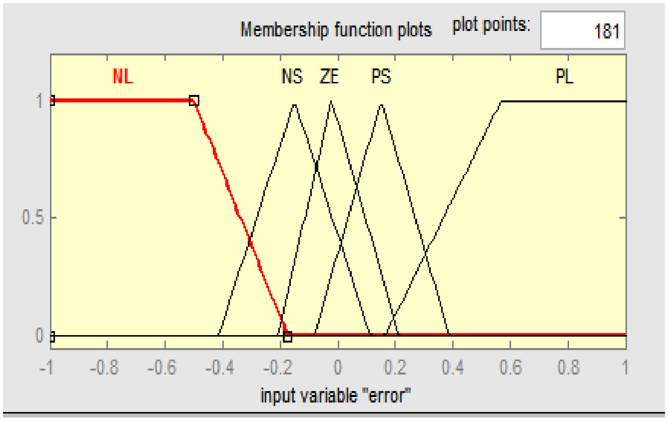


Fig. 3 the member ship of error

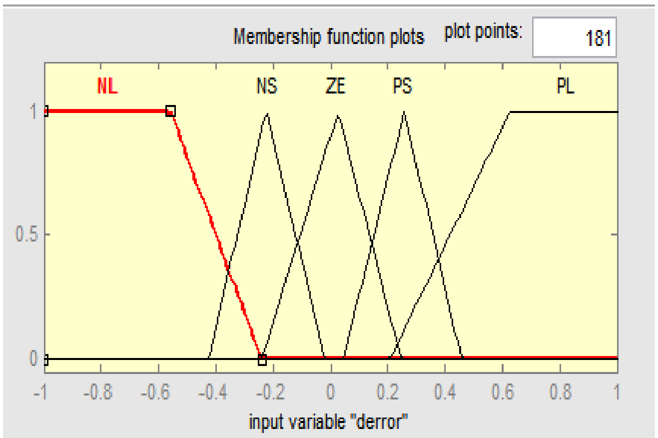


Fig. 4 the member ship of change of error

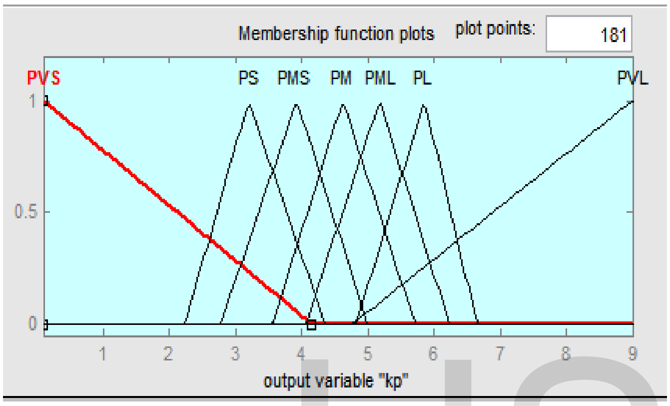


Fig. 5 the member ship of KP , KI, KD.

Rule Base for fuzzy tuning PID parameters

Table 2. Rule base for tuning K_P Parameter

Δe \ e	NL	NS	ZE	PS	PL
NL	**PVL**	**PVL**	**PVL**	**PVL**	**PVL**
NS	**PML**	**PML**	**PML**	**PL**	**PVL**
ZE	**PVS**	**PVS**	**PS**	**PML**	**PMS**
PS	**PML**	**PML**	**PML**	**PL**	**PVL**
PL	**PVL**	**PVL**	**PVL**	**PVL**	**PVL**

Table 3. Rule base for tuning K_I Parameter

Δe \ e	NL	NS	ZE	PS	PL
NL	**PM**	**PM**	**PM**	**PM**	**PM**
NS	**PMS**	**PMS**	**PMS**	**PMS**	**PMS**
ZE	**PS**	**PS**	**PVS**	**PS**	**PS**
PS	**PMS**	**PMS**	**PMS**	**PMS**	**PMS**
PL	**PM**	**PM**	**PM**	**PM**	**PM**

Table 4. Rule base for tuning K_D Parameter

Δe \ e	NL	NS	ZE	PS	PL
NL	**PVS**	**PMS**	**PM**	**PL**	**PVL**
NS	**PMS**	**PML**	**PL**	**PVL**	**PVL**
ZE	**PM**	**PL**	**PL**	**PVL**	**PVL**
PS	**PML**	**PVL**	**PVL**	**PVL**	**PVL**
PL	**PVL**	**PVL**	**PVL**	**PVL**	**PVL**

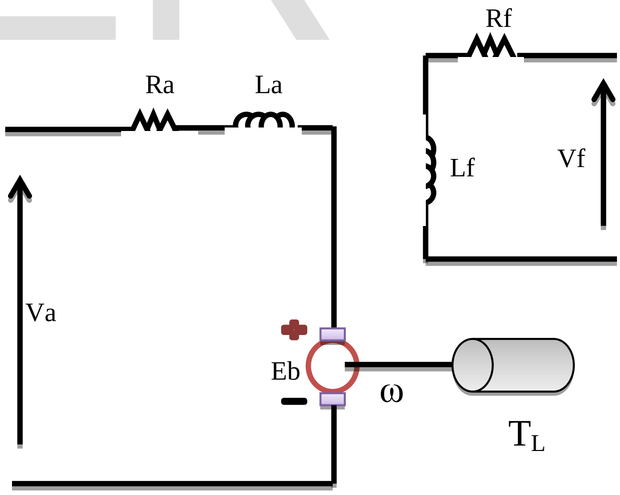
IV. DC Motor Drive

DC Motor consist of stator which include form the generation winding to the magnetic field and the rotor include form the armature winding. The field (stator) circuit of the motor is exciting by a constant source, The speed of a DC motor can be controlled by varying the voltage applied to the armature winding terminal the way about the buck Converter, The steady state speed of the motor can be described as [1]:

$$\omega = \frac{v_a - i_a * R_a}{k_b} \qquad \text{......... (7)}$$

Where k_b (is the back emf constant), Ra (armature resistance), Ia ,Va (armature current & voltage respectively), and ω (angular velocity).

The fig.(6) explain the equivalent circuit of the separately excited DC motor



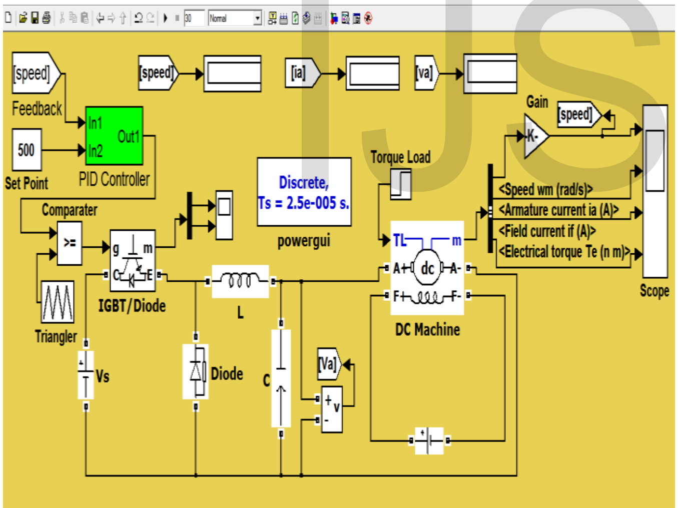
The fig. 6 separately excited of DC motor

Table 5 parameter of Drive system

Parameter	Values
Armature voltage (Va)	**220 volt**
Field voltage (Vf)	**220 volt**
Armature Resistance (Ra)	**2.3 Ω**
Field Resistance (Rf)	**550 Ω**
Armature inductance (La)	**$20 * 10^{-3}$ H**
Field inductance (Lf)	**8.5 H**
Speed rated (ω)	**1000 rpm**
Full load (T_L)	**8 n.m**
Moment of inertia (J)	**0.041 kg.m^2**
Viscous friction (B)	**0.002 n.m/rad/sec**
The capacitor of Buck Converter (c)	**1000 µ farad**
The inductance of Buck Converter (L)	**$30 * 10^{-3}$ H**

V. SIMLATION RESULTS

The simulation of control system in matlab program . The control system consist of the buck converter circuit , the pulse generating circuit , the controller which consist of two types : PID controller and fuzzy tuning PID controller, and the DC motor as shown in fig. 7.



The fig.7 explain the simulation system in MATLAB program

A. *PID controller tuning method (trial and error)*

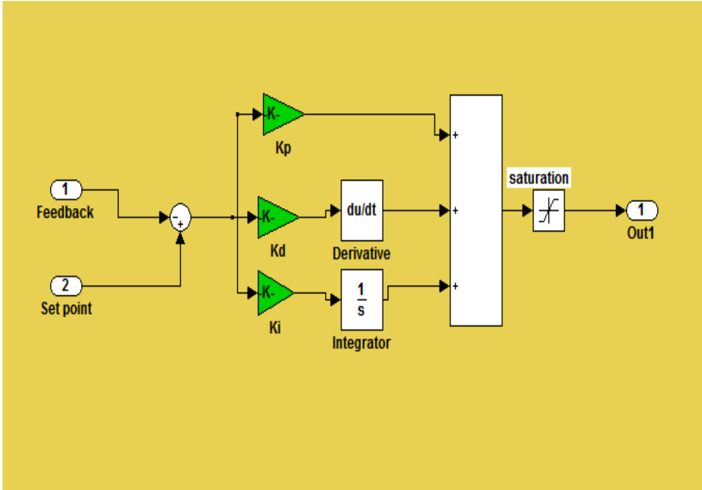


Fig. 8 the structure of PID controller

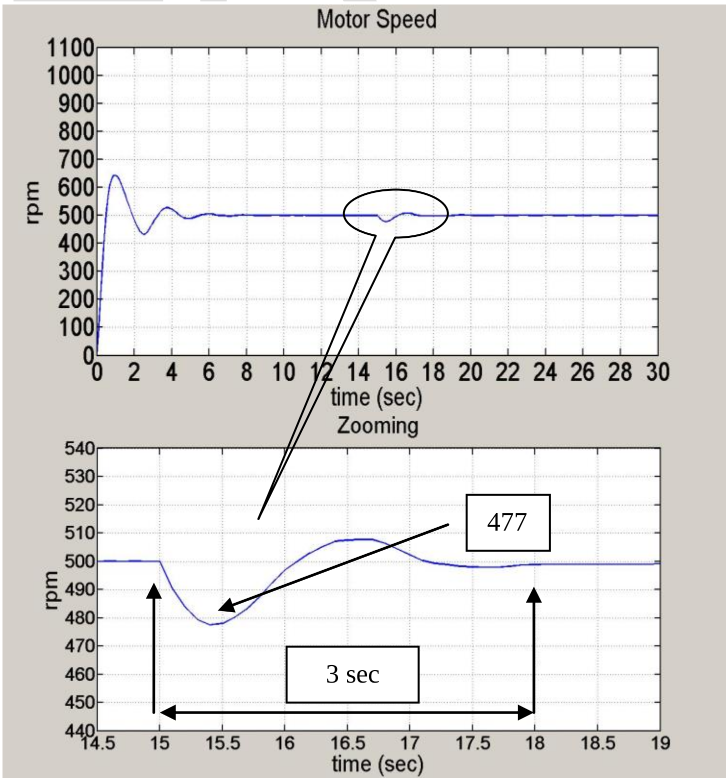
The PID parameters are

$K_P = 0.35$

$K_I = 1.8$

$K_D = 0.18$

The fig. 9 explain the speed response of DC motor at speed 500 rpm and apply sudden load (27% of full load) at time 15 sec.



The fig. 9 DC motor speed at 500 rpm with apply sudden load using conventional PID controller

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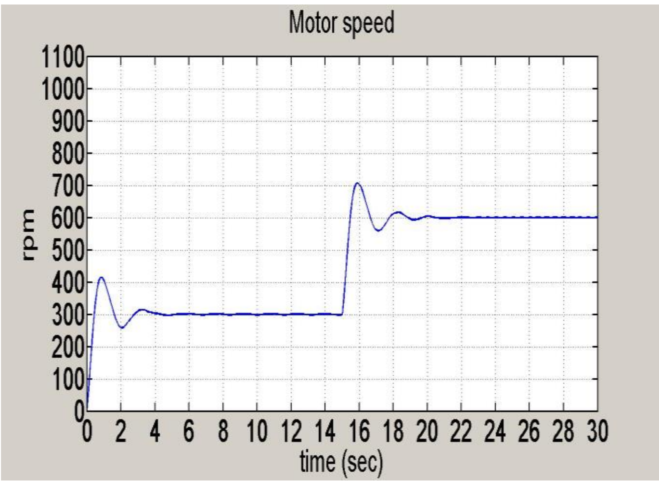
The fig. 10 explain the speed response of DC motor at speed change from 300 rpm to 600 rpm at time 15 sec with no load.



The fig. 10 DC motor speed at change speed reference of 300 rpm to 600 rpm with no load using conventional PID controller

B. Fuzzy tuning PID Parameters

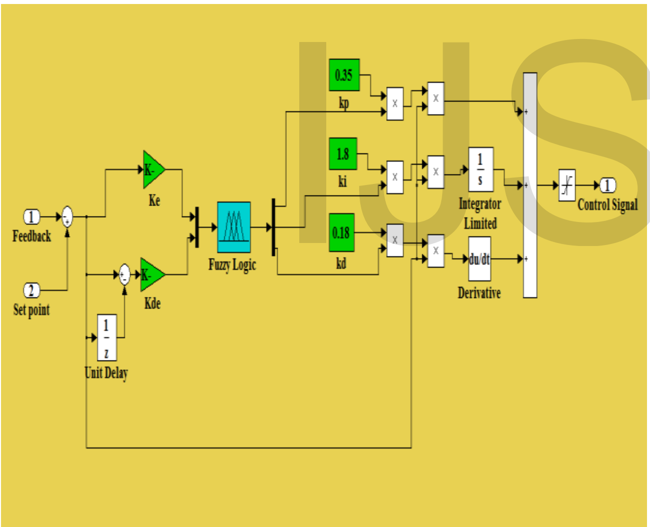
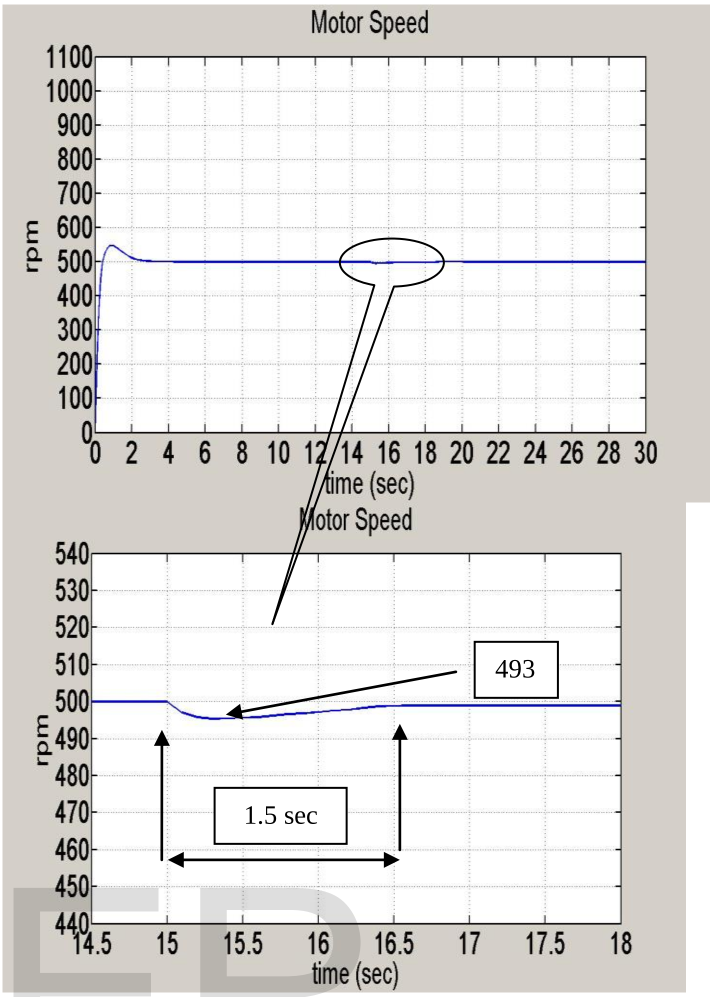


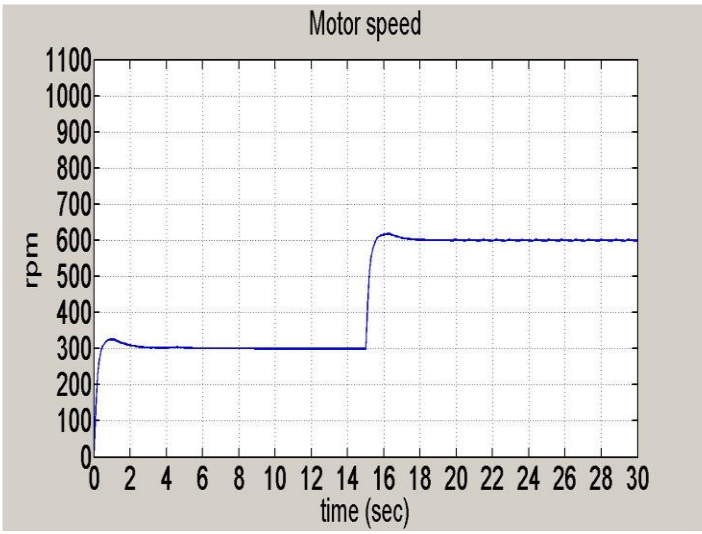
Fig. 11 the structure of fuzzy tuning PID controller

The fig. 12 explain the speed response of DC motor at speed 500 rpm and apply sudden load (27% of full load) at time 15 sec.



The fig. 12 DC motor speed at 500 rpm with apply sudden load using fuzzy tuning PID controller

The fig. 13 explain the speed response of DC motor at speed change from 300 rpm to 600 rpm at time 15 sec with no load.



The fig. 13 DC motor speed at change speed reference of 300 rpm to 600 rpm with no load using fuzzy tuning PID controller

Table 6 explain the performance simulation system between conventional (Classical) PID and fuzzy tuning PID controller.

Tuning Method of PID	Speed (rpm)	P.O.S %	Time settling (ts) sec	Time Rise (tr) sec	Ess %
Classical	300	38.2	4.1	0.42	0
Classical	500	28.5	6.5	0.48	0
Fuzzy logic	300	7.13	2.3	0.48	0
Fuzzy logic	500	9.4	2.2	0.53	0

Table 7 explain the performance the back time between conventional PID and fuzzy tuning PID controller in state apply sudden load on DC motor (27% of full load) on speed 500 rpm.

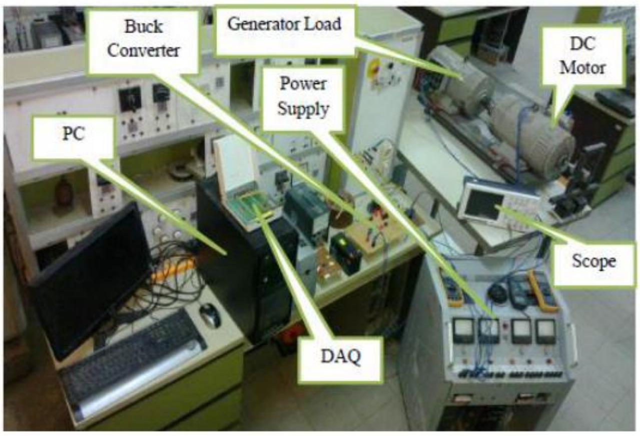
Tuning Method of PID	Implementation Method	Speed (rpm)	Settling Time Ts (sec)
Classical	Simulation	500	3
Fuzzy logic	Simulation	500	1.5

Table 8 explain the performance between conventional PID and fuzzy tuning PID controller in state change reference speed from 300 rpm to 600 rpm.

Tuning Method of PID	Implementation Method	P.O.S %	Time settling (ts) sec	Time Rise (tr) sec	Ess %
Classical	Simulation	34.32	5.2	0.47	0
Fuzzy logic	Simulation	6	3.7	0.55	0

VI. Practical Results

The practical implementation of control system using Labview program . The control system consist of the buck converter circuit , the pulse generating circuit , the controller which consist of two types : PID controller and fuzzy tuning PID controller, isolation circuit , tacho generator circuit , DAQ circuit, and the DC motor as shown in fig. 14. in laboratory.



The fig. 14: explain the system in laboratory

A. PID controller tuning method in Labview (trial and error)

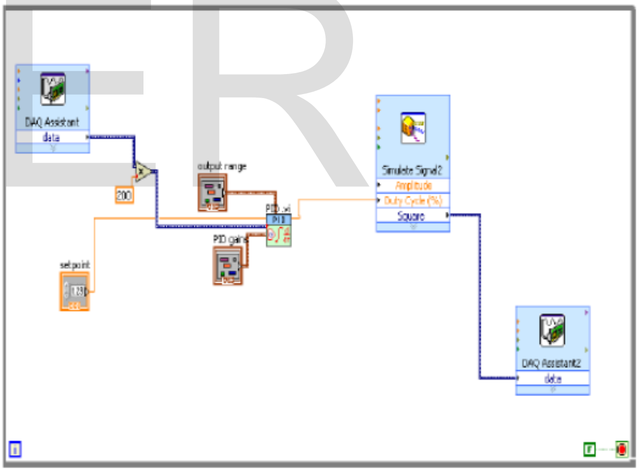


Fig. 15: the structure of PID controller in Labview program

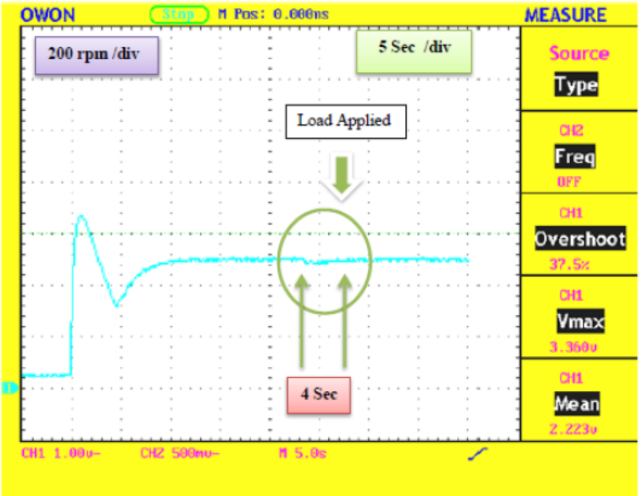
The PID parameters are :

$K_P = 0.35$

$K_I = 1.8$

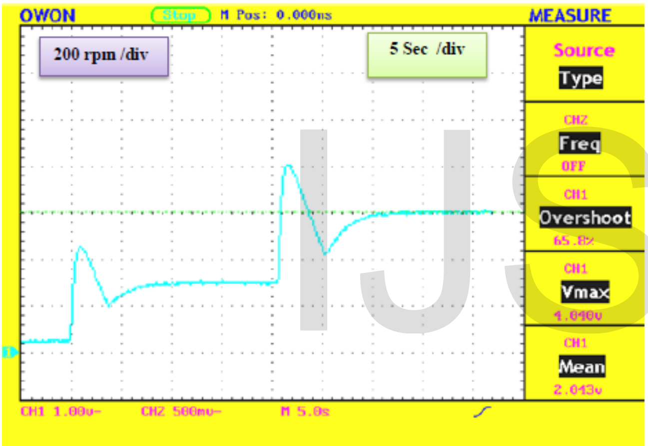
$K_D = 0.18$

The fig. 16 explain the speed response of DC motor at speed 500 rpm and apply sudden load (27% of full load) .



The fig. 16: DC motor speed at 500 rpm with apply sudden load using conventional PID controller

The fig. 17 explain the speed response of DC motor at speed change from 300 rpm to 600 rpm with no load.



The fig. 17: DC motor speed at change speed reference of 300 rpm to 600 rpm with no load using conventional PID controller

B. Fuzzy tuning PID Parameters in labview program

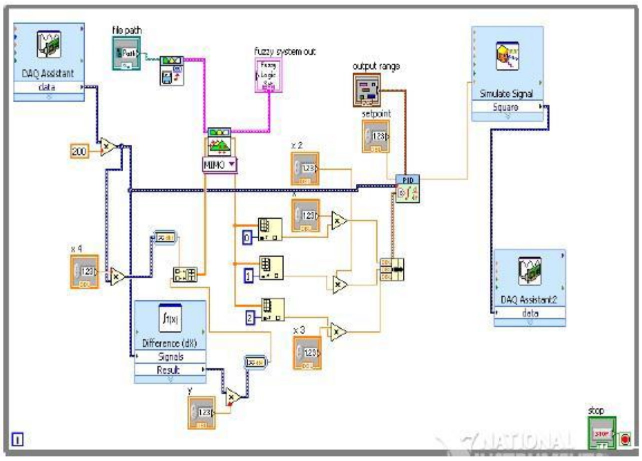
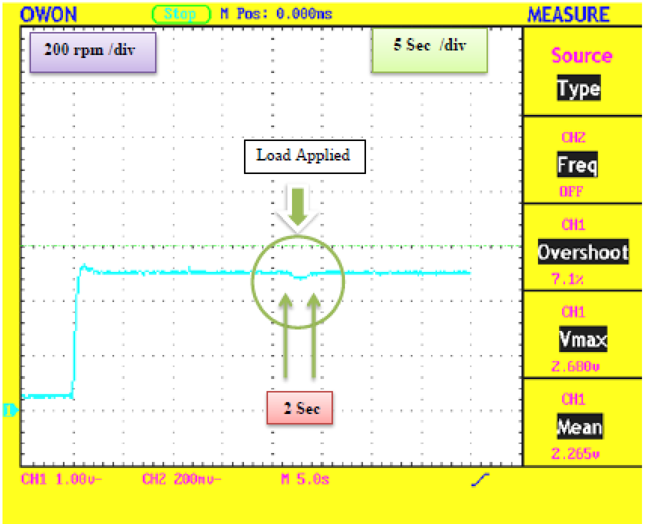


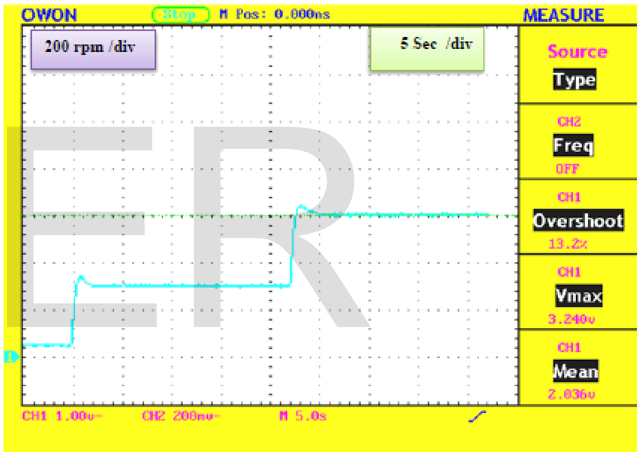
Fig. 18: the structure of fuzzy tuning PID controller in Labview program

The fig. 19 explain the speed response of DC motor at speed 500 rpm and apply sudden load (27% of full load).



The fig. 19 DC motor speed at 500 rpm with apply sudden load using fuzzy tuning PID controller.

The fig. 20 explain the speed response of DC motor at speed change from 300 rpm to 600 rpm with no load.



The fig. 20 DC motor speed at change speed reference of 300 rpm to 600 rpm with no load using fuzzy tuning PID controller

Table 9 explain the performance practical system between conventional (Classical) PID and fuzzy tuning PID controller.

Tuning Method of PID	Speed (rpm)	P.O.S %	Time settling (ts) sec	Time Rise (tr) sec	Ess %
Classical	**300**	**36.6**	**7.5**	**0.3**	**0**
Classical	**500**	**26**	**10**	**0.37**	**0**
Fuzzy logic	**300**	**5.33**	**2**	**0.47**	**0**
Fuzzy logic	**500**	**8**	**2.5**	**0.52**	**0**

Table 10 explain the performance the back time between conventional PID and fuzzy tuning PID controller in state apply sudden load on DC motor (27% of full load) at speed 500 rpm.

Tuning Method of PID	Implementation Method	Speed (rpm)	Settling Time Ts(sec)
Classical	**Practical**	**500**	**4**
Fuzzy logic	**Practical**	**500**	**2**

Table 11explain the performance between conventional PID and fuzzy tuning PID controller in state change reference speed from 300 rpm to 600 rpm.

Tuning Method of PID	Implementation Method	P.O.S %	Time settling (ts) sec	Time Rise (tr) sec	Ess %
Classical	**Practical**	**65**	**9**	**0.26**	**0**
Fuzzy logic	**Practical**	**16.66**	**3**	**0.43**	**0**

VII. Conclusions

Fuzzy tuning PID controller is good performance compared to conventional PID tuning method. The three parameters K_P, K_I, and K_D of PID controller need to tuning and adjust online in order to achieve better controller performance. Fuzzy tuning PID parameters can automatically Adjust PID parameters in accordant to the speed error and the change of speed error, so it has better self-adaptive capacity fuzzy PID parameters has smaller overshoot and settling time than conventional PID tuning method .

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