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Digital Fractional PID Speed Controller for Seperately Excited DC Motor

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ABSTRACT: This paper presents digital fractional order proportional integral derivative (FO-PID) has designed to controller speed of separately excited Direct current (DC) motor fed by a buck converter. The performance of the DC motor is better with FO-PID controller.in a fractional order PID controller there are two new variables integral-differential operator μ & β.The five parameter (K_pK_i, Kd, μ & β) of the FO-PID controller are increases the performance of control scheme. Fractional order controller is also used for many industrial applications, to developed methods for controller design & parameter tuning & efficient strategies for controller implementation. The five parameters are firstly find out by frequency analysis and secondly time domain analysis. A model is developed for speed control of separately excited DC motor. Genetic algorithm is used for tuning of fractional PID controller.

KEYWORDS: electric drives,buck converter,fractional order PID controller,speed control,Digital controller

I.INTRODUCTION

An extensive research has been carried in area of high-performance motor drives for industrial applications. Though more robust, energy efficient and high performance drives are in demand for many industrial applications such as electric vehicles, steel rolling mills and electric cranes, etc. DC motors has been the primary means of these applications, due to precise, simple control characteristics, cost effective than those of AC Motors [1]. The speed of DC motor is controlled by Field flux control, Armature voltage control, Proportional Integral (PI) Controller, Proportional Integral Derivative (PID) Controller and intelligent control which uses various Artificial Intelligence (AI) computing approaches like neural networks, fuzzy logic, evolutionary computation and genetic algorithms to control a system[2]. PID based control is preferred in many industrial applications because of their simple structure and has many advantages like less settling time, fast control and low cost. Owing to the high achievement, simplicity of design and implementation of PID controllers, many researchers worked to enhance the performance of these controllers[2]. In recent studies, a new extension to PID controller is put together, with the help of integrations and differentiations based on Fractional Calculus. This control technique popularly known as Fractional order PID (FOPID), is used for the speed control of DC motor drive. The idea of fractional calculus application to control theory, and shows the advantages of their applications in motor control, magnetic levitation, process control, etc. The fractional order systems have a memory element being considered infinite dimensional, while the integer order systems have a limited memory (finite dimensional) provides smooth control, owing to improved filtering action [4].The development of larger performance motor drives is important in industrial applications such as steel rolling mills, electric trains and robotics. Generally, a high performance motor drive system must have good dynamic speed control and load regulating response to perform task. DC electrical drives are mostly used because of their simple in construction , used for number of applications, high reliabilities, flexibilities and less cost and have more industrial applications, home appliances where speed and position control of motor are required. DC drives are less complex with a single power conversion from AC to DC. The speed torque characteristics of DC motors are much more superior to that of AC motors. A DC motors provide better control of speed for acceleration and deceleration. DC drives are normally less expensive for more horsepower ratings [5]. DC motors have a long history of use as adjustable speed machines and a wide range of options have evolved for this purpose.[6] In these applications, the motor should be controlled to give the desired performance. The controllers of the speed have goal to control the speed of DC motor to execute number of tasks, there is several controller types, the controllers can be: proportional integral (PI), proportional integral derivative (PID).The proportional – integral – derivative (PID) controller operates the majority of the control system in the world.[8] It has been reported that more than 95% of the controllers in the industrial

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process control applications are of PID type having the simplicity, clear functionality, applicability and ease of use offered by the PID controller. PID controllers provide dynamic and better performance for most systems if the PID parameters are tuned properly.[9]

The problems in applying a regular control algorithm (PI, PD, PID) in a speed controller are the effects of non-linearity in a DC motor. The characteristics such as nonlinearity of a DC motor such as saturation and friction is degrade the performance of conventional controller's .An accurate nonlinear model of an actual DC motor is so difficult to find and parameter obtained from systems identification may be only approximated values.[10]

This work is summarized in the following manner: section II describes the plant; Design procedure of the proposed digital Fractional order PID control with details of pole zero approximation method and particle swarm optimization techniques is discussed in section III; In section IV simulation details are provided; In section V description of hardware module is given; the comparison of proposed controller, hardware implementation and results are presented in section VI. Summary and conclusion are given in section VII. List of symbols and parameters are given in table I.

TABLE I LIST OF SYMBOL AND PARAMETERS

Abbreviation	***Parameters with Unit***
E_a	Armature Voltage(V)
V_f	Field Voltage (V)
R_a	Armature Resistance (Ohm)
J	Moment of Inertia (Kg-m^2)
K_t	Torque Constant
I_a	Armature Current (Amp)
I_f	Field Current (Amp)
L_a	Armature inductance (Henry)
f	Viscous friction coefficient (N-m-s)
K_b	Back emf constant (N-m Amp)
Wm	Motor speed (rad/sec)
T	Motor torque (N-m)
Tf	Static friction torque (N-m)
Jm	Rotational inertia (Kg-m^2)
Bm	Viscous friction (Kg/m.s)

II.LITERATURE SURVEY

DC motor is a power actuator,which converts electrical energy into rotational mechanical energy.DC motor is mostely used in industry and commercial application such as tape motor,diskdrive,robotic manipulators and in numerous control applications.[1] therefore,its control is important. for the control of DC motor number of techniques are used.DC motor is controlled by a digital fractional-order PID (FO-PID) control.[2] FO-PID controller improve the performance and robustness of the system.[3].

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III.MODELING OF THE DC MOTOR AND BUCK CONVERTER

A.Transfer function of armature controlled DC motor

A separately excited DC motor consist of a armature winding and field winding having separate DC supply for Armature winding as well as field winding. Schematic diagram of separately excited DC motor is shown in fig.1. The field winding is excited by a field voltage Vf and field current If. Input DC voltage Ea is given to the armature winding and armature current Ia flowing from winding.by working principal a DC motor develops a Back emfEb and a torque T which balance load torque Tl .The general transfer function of armature controlled DC motor is given by equation (1).The parameters of separately excited DC motor is found out by taking retardation test, load test and VA method on DC motor. The transfer function of DC motor with experimental values are given in equation (2) [1].Specification of DC motor is given in appendix.

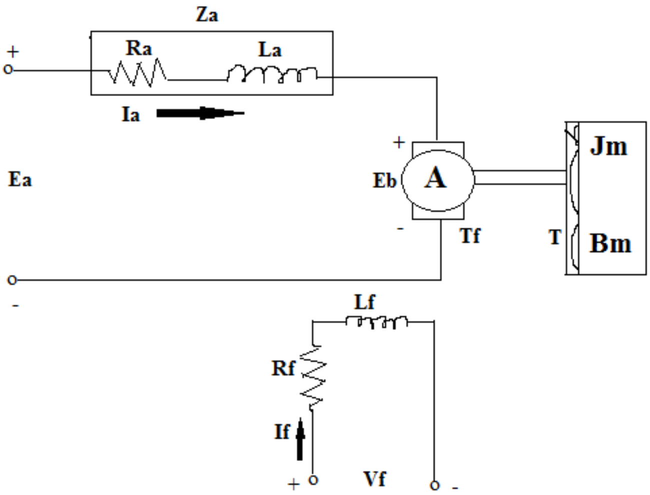

Fig.1.Scematic diagram of separately excited DC motor.

Steps to find out transfer function of DC motor

1.Writea electrical equation.

2.Write a mechanical equation.

3.Use the electromechanical relationships to couple the both equations.

Electrical Equation is given by,

$$I_a(s) = \left[\frac{1}{L.s + Ra}\right][E_a(s) - E_b(s)] \qquad (1)$$

$$\underline{\omega}_m(s) = \left[\frac{1}{Jm.s+Bm}\right].T(s)(2)$$

$$\left[\frac{\underline{\omega}(s)}{Ea(s)}\right] = \frac{Kt}{(La.s + Ra)(Jm.s + Bm) + Kt.Ke} \quad (3)$$

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This above equation is consider as $G_1(s)$,

$$G_1(s) = \frac{1.354}{0.001602s^2+0.1765s+2.035} \quad (4)$$

B. Buck Converter Model

A Buck converter (step down converter) is a Dc to DC power converter which step down voltage or step up current from its input supply to its output. It is a class of switched mode power supply (SMPS) typically containing at least two semiconductors and one enery storage element capacitor, inductor or two in combination. Here we use a buck converter having MOSFET, diode and capacitor for energy storage. The change in duty cycle of PWM signal is regulate the voltage of armature winding of the DC motor. Figer .2 given below shows the representation of Buck converter.

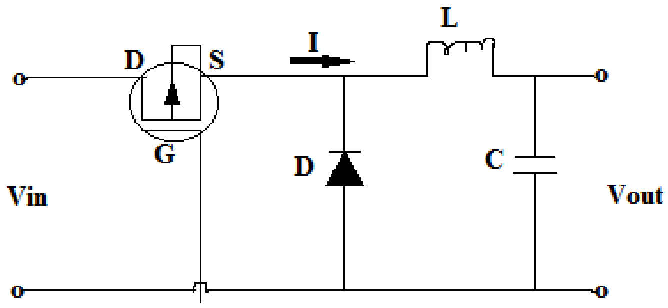

Fig.2.Scematic diagram of buck converter

Transfer function of buck converter is find out by considering above figure.2[1].

Vin is the input DC voltage and Vout is the output DC voltage of buck converter .I is the current flowing from inductor L and is given by the following equation,

$$\left[\frac{\mathrm{I(s)}}{\mathrm{V(s)}}\right] = \left[\frac{Cs}{LCs+1}\right] \quad (5)$$

Now the transfer function of buck converter is the ratio of Laplace transform of output voltage Vout(s) to the Laplace transform of input voltage Vin(s) and given by,

$$\left[\frac{V_{out}(s)}{V_{in}(s)}\right] = \frac{\frac{1}{Cs}.\mathrm{I(s)}}{\left(\frac{(LCs^2+1)}{Cs}\right).\mathrm{I(s)}} \quad (6)$$

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$$\left[\frac{V_{out}(s)}{V_{in}(s)}\right] = \frac{1}{(s^2LC+1)} \quad (7)$$

$$G_2(s) = \frac{1}{(s^2LC+1)} \quad (8)$$

$$G_2(s) = \frac{8.5106*10^4}{s^2+8.5106*10^4} \quad (9)$$

The combined transfer function of DC motor and Buck converter given below,

$$G(s) = G_1(s) * G_2(s) \quad (10)$$

$$G(s) = \frac{1.152*10^5}{0.0016s^4+0.1765s^3+138.2s^2+15020s+173200} \quad (11)$$

The step input is applied to the G(s).

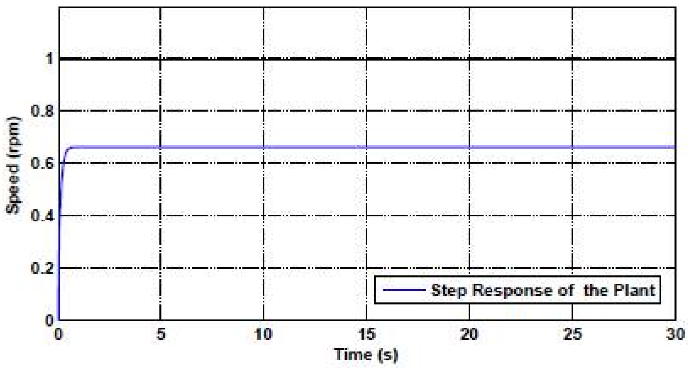

Fig.3.Step response of the plant

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IV.DIGITAL FRACTIONAL ORDER PID CONTROLLER

Digital fractional Order PID controller is an extension of conventional PID controller which is based on the theory of fractional calculus [3]. The Digital fractional controller is the integer order PID controller .This can control real world processes more accurately with small control system. The Digital FOPID controller has five parameters which increases flexibility and system become more robust [2]. A fractional order system is given by the following fractional order differential equation[6,7]

$$D^{\mu n}f(t) + D^{\mu n-1}f(t) + \cdots = D^{\beta n}f(t) +$$

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$$+ D^{\beta n-1} f(t) + \cdots \qquad (12)$$

Where,

$D^{\mu n}$=0 is called the fractional derivative of order μn with respect to variable t with starting point at t=0.The FO-PID controller can be described by the fractional order differential equation

$$r(t) = K_p e(t) + K_i D^{-u} e(t) + K_d D^{\beta} e(t) \qquad (13)$$

Now, applying Laplace transform, the transfer function of fractional order PID controller is given by;

$$C(s) = K_p + K_i s^{-\mu} + K_d s^{\beta}, (\mu, \beta) > 0 \qquad (14)$$

Where, K_p is the proportional constant, K_i is an integral constant,K_d is the derivative constant, and μ,β are positive real numbers.

The Fractional order controllers are of infinite order, in case of integer due to that there is need to approximate into finite dimensional system. Artificial intelligence (AI) optimization methods like genetic algorithm, differential evolution, ant colony optimization and particle swarm optimization[8,10,11].

TABLE II

GA OPTIMIZED CONTROLLER PARAMETERS (μ: ORDER OF INTEGRATOR, β: ORDER OF DIFFERENTIATOR)

Sr.No.	**Controllers**	**Gain and Fractional Order Value**				
		K_p	K_i	K_d	μ	β
1.	PID	51	45	0.025	1	1
2.	FOPID	7.24	2.33	0.65	0.75	0.25

A. Design Steps of FO-PID controller

1. Range of frequency (ω_l, ω_h) controller is given from open loop bode plot as in fig .4.
2. The order of approximation N is decided.
3. K_p, K_i, K_d, μ, β values are obtained using GA tuning method.
4. The controller transfer function (14) as in computed using the parameters obtained as in step 3.
5. Equation no. (14) Is approximated using Oustaloup's approximation method.
6. The approximated controller transfer function is used in figure 4 and the speed response of DC motor is observed.

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V.SPEED CONTROL OF DC MOTOR

Fig.4 shows a schematic diagram of closed loop speed control of DC motor drive. In these control method conventional PID and Fractional Order PID controllers are considered for the DC motor electric drive speed control. A reference speed is given as an input and controller gives the control signal is proportional to the error generated in control scheme. These control signal is give as input to the PWM module. Then the PWM pulses are generated by comparing the reference input signal with the input wave of the switch of buck converter. The IR speed sensor is used to sense the speed of motor .The simulation is carried out on the MATLAB software.

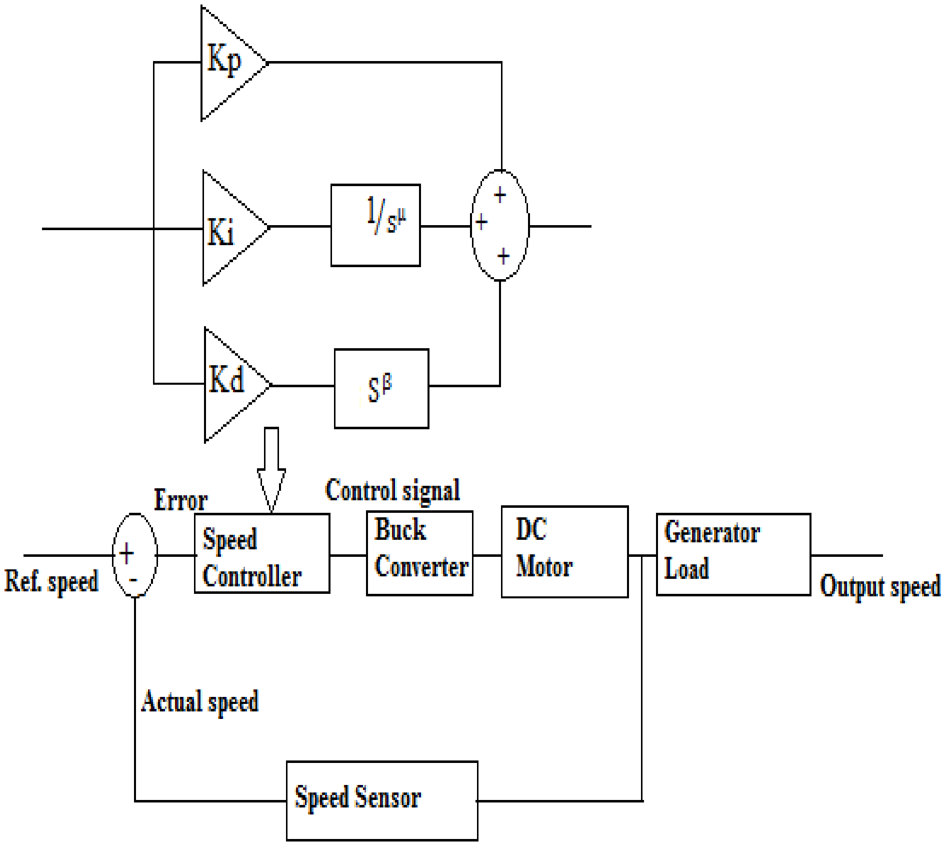

Fig. 4.Schematic diagram of speed control of DC motor

VI.RESULTS AND DISCUSSION

The performance of PID and Fractional Order PID controller on the DC motor is studied by using the time domain and frequency domain analysis. The bode plot analysis is used for controlled plant. Fractional Order PID controlled system is more stable, as the gain margin and phase margin values are higher compared to PID controlled system.Fig.5. shows the speed respone of Fractional PID and conventional PID controller at 1000 rpm.Fig.6 shows the the speed respone of Fractional PID and conventional PID controller at 900 rpm.

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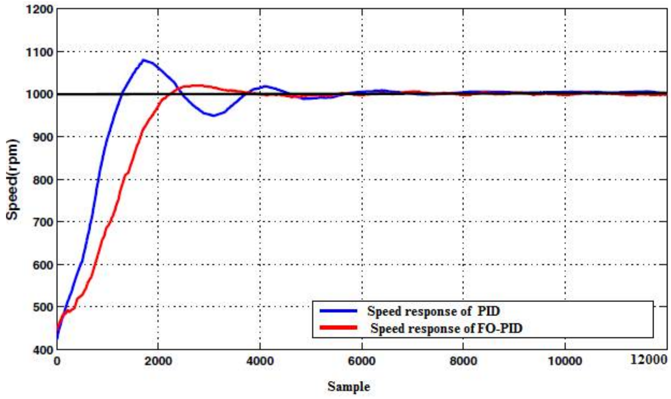

Fig.5.Speed response at reference speed 1000 rpm

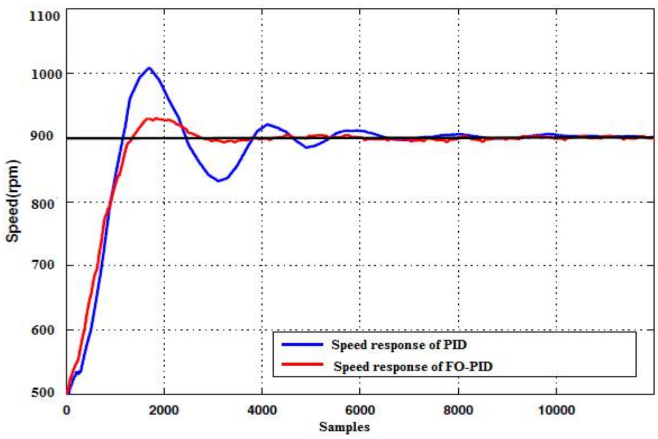

Fig.6.Speed response at reference speed 900 rpm

Fig.7 shows the unit step response of PID controller and Fractional Order PID controller with increase in gain 10% to 50 %.if gain increases then from these figure we understand the graph of FO-PID controller shows the better speed control characteristics.

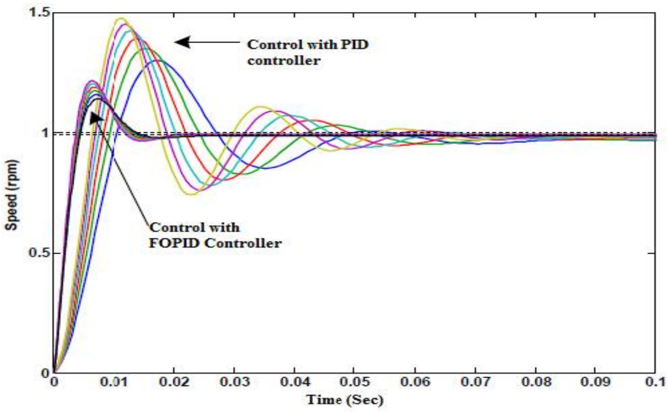

Fig.7.Unit step response of PID Controller and FOPID Controller with gain increases from 10% to 50%

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Fig.8 shows the PWM signal input given to the controller these clearly shows the duty cycle of PWM signal and depend on these there is speed control of DC motor.

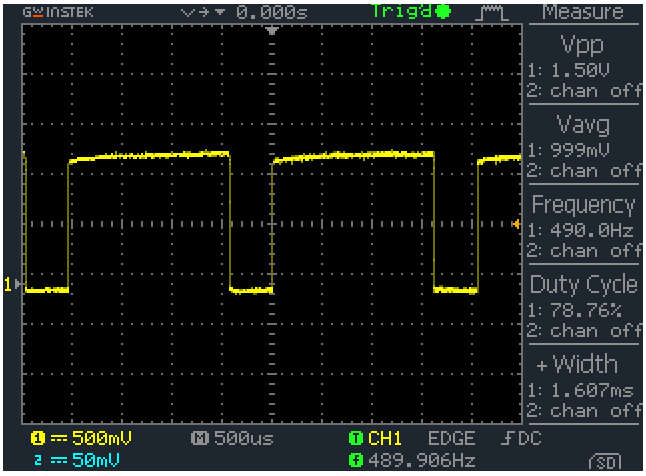

Fig.8.PWM signal input of FO PID controlled DC Motor

VII.CONCLUSION

This paper presents an application of Digital Fractional order PID based design of Speed controller for DC Electrical Motor drive. The standalone digital FO-PID controller is implemented on arduino ATMEGA 328.The details of the design and hardware implementation is given in paper. The performance analysis based on real time value of the speed for integer order and fractional order controller gives the speed response improvement in case of FOPID controller as compared to conventional PID controller. The proposed controller considerably improves the performance of the speed control system and also increases robustness of the system. The simulation result is compared in both PID and Fractional PID controller in MATLAB software. The speed control is achieved with lesser effort using FOPID controller and increases the efficiency of all over control system.

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APPENDIX

TABLE III

DC MOTOR SPECIFICATION

Parameter	**Value**	**Parameter**	**Value**
Power (P)	45 W	Rated Speed(N)	1000
Armature Voltage(E_a)	12 V	Armature Current (Ia)	2.9 A
Field Voltage(V_f)	12 V	Field Current (I_f)	0.65A
Armature Resistance(R_a)	2.5 Ω	Armature Inductance (La)	8 mH

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Moment of Inertia (J)	0.04578	Viscous Coefficient(f)	0.01579
Torque Constant (K_t)	1.354	Back EMF Constant (Kb)	1.458
Frame	112	Winding	Shunt

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