التحكم في سرعة محرك تيار مستمر مغذي بواسطة مقطعات (Chopper DC) باستخدام وحدة التحكم PID لاستخدامه في تطبيقات القيادة الصناعية

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الملخص :

لعب التحكم الآلي دورًا حيويًا في تقدم الهندسة والعلوم في الوقت الحاضر في الصناعات ، ويعد التحكم في محرك التيار المباشر (DC) ممارسة شائعة وبالتالي فإن تطبيق التحكم في سرعة محرك DC أمر مهم .الغرض الرئيسي من التحكم في سرعة المحرك هو الحفاظ على دوران المحرك بسرعة محددة مسبقًا وقيادة النظام بالسرعة المطلوبة .في هذه الورقة تم اقتراح تصميم مبسط للتحكم في سرعة DC محرك ذو تهييج منفصل (SEDC) يتغدى من محول جهد مستمر. طرق التحكم في السرعة في SEDC إما عن طريق تغيير جهد المحرك ، أو عن طريق تغيير تدفق الحقل) تيار المجال (لمحرك DC للحصول على السرعة بالقيمة المستهدفة .يتم استخدام طريقة جهد المحرك في هذا المشروع حيث يعطي المروحية جهد الدخل المطلوب للمحرك .دائرة إطلاق المروحية التي تتلقى إشارة من وحدة تحكم PID لتغيير جهد الدخل لمحرك DC لتحقيق السرعة المطلوبة .تحكم PID يختار قاعدة المعلومات الخاصة به عن طريق التجربة والخطأ .المتوقع من هذا البحث هو الحصول على السرعة المطلوبة وقيادة المحرك بهذه السرعة .يتم تطبيق نموذج المحاكاة في MATLAB / SIMULINK تحت سرعات متفاوتة لإظهار أدائها وتشير النتائج إلى أن مخططات التحكم المقترحة لدينا لديها أداء جيد.

Speed Control of Chopper Fed DC Motor Using PID Controller for Industrial Drive Application

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Abstract

The automatic control has played a vital role in the advance of engineering and science. Nowadays in industries, the control of direct current (DC) motor is a common practice thus the implementation of DC motor of controller speed is important. The main purpose of motor speed control is to keep the rotation of the motor at the preset speed and to drive a system at the demanded speed. In this paper, a simplified speed control design of chopper fed separately excited DC motor (SEDC) drive is proposed. The speed control methods of SEDC are either by varying the armature voltage, or by varying field flux of DC motor to obtain the speed at the target value. Armature voltage method is used in this project in which chopper gives the desired input voltage for the motor. The firing circuit of chopper receiving signal from PID controller to change the input voltage of DC motor to achieve the desired speed. PID controller chooses its parameters base on trial and error method. The expectation of this project is to get the precise the demanded speed and to drive a motor at that speed. The simulation model is implemented in the MATLAB/SIMULINK under varying speed to

demonstrate its performance and results indicate that our proposed control schemes have good performance.

Keywords— DC Chopper**,** separately excited DC motor, armature voltage control, PID controller.

1. Introduction

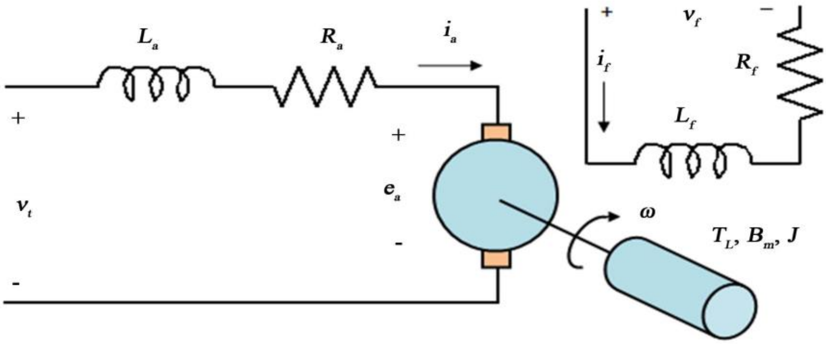
The dc motors are used in various applications such as industries, robotics etc. The preferences are because of their simplicity, ease of application, reliability and favourable cost have long been a backbone of industrial applications. DC drives are less complex with a single power conversion from AC to DC. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition used as adjustable speed machines and a wide range of options have evolved for this purpose. In these applications, the motor should be precisely controlled to give the desired performance. Many varieties of control schemes such as P, proportional integral (PI), proportional derivation integral (PID), adaptive, fuzzy logic controller (FLCs) and Artificial Neural Networks (ANNs) have been developed for speed control of dc motors. Syllignakis J (2016) presents a simple speed control application for a DC motor in laboratory use. The purpose of this application is to maintain the desired speed on a generator operating on the same axis to the motor [3]**.** Wisam Najm Al-Din Abed (2015) designed and simulated an armature and field control systems using state feedback controller based on bacterial foraging optimization technique for controlling the speed of separately excited dc motor (SEDM). First the SEDM is simulated feeding back the armature current and angular speed (armature control method), second the SEDM is simulated with feeding back the field current and angular speed (field control method). For both controlling methods the controller's gains are tuned [4]. Vijay Singh et al (2014) In their paper, the performance of DC motor is tested/ evaluated with conventional controller such as PID controller and the results have been compared with the fuzzy based PID controller. When compared to conventional controller they found that Fuzzy based PID controller provides better speed response but conventional controller provides better speed response by changing load at the cost of very long settling time. MATLAB/SIMULINK environment is discussed to verify the above investigation [5]. Ch.Chengaiah et al (2013) The attempt is made to simulate a speed control of SEDC with PID and fuzzy controller. The aim of this paper is providing efficient method to control speed of DC motor using analog controller. With the availability of MATLAB/SIMULINK, fuzzy Controller for comprehensive study of modeling analysis and speed control design methods has been demonstrated [6]. Venkateswarlu and Chengaiah (2013) made an attempt to simulate a speed control of SEDC with PID and fuzzy controllers. The aim of their paper was to provide an efficient method to control speed of DC motor using analog controller. Their work was able to show that fuzzy controller performs better if well modelled applied [7]. Atul K Dewangan et al (2012), have design a system, based on the speed controlling of a DC motor, with a constant speed at any load condition. For that purpose they use PWM and DC chopper [8]. Hamid Saeed Khan and Muhammad Bilal Kadri (2013), they have present an implementation of digital PI controller on an 8-bit microcontroller. This PI controller is tested for the plant model of

DC motor by hardware-in-loop simulation technique. The controller attempts to minimize the error by adjusting the plant control input. The main reason of using ATMEL 8051 microcontroller is its easy use and low cost [9]. ManuelGuerreiro and Daniel Foito (2007) have designed a model in which speed was controlled using sliding mode with a first order differential equation based on the speed error. The result of the switching function was integrated with a current limitation using a logic equation [10]. Jeetender Singh Chauhan and Sunil Semwal (2013), have shown in their paper, how a RS-232 is used to control speed of DC motor. In this paper, PWM based speed control of DC motor through RS232 with PC goal of this as role of electrical drives is a major concern in industrial automation [11]. Shumei Zhang et.al (2011) use of an adaptive PID controller to reduce a DC motor speed pulsation such that the robust stability for the closed- loop system is guaranteed. The PID control scheme tunes the PID controller parameters by using the theory of adaptive interaction. Aneural network was applied in the adaptive algorithim to regulate a set of PID controller parameters by minimizing an error function[12].

The most issue discusses in speed controller is regarding their efficiency and reliability. The efficiency element is important in order to save cost. The efficiency of speed controller is depending on method control system. The speed controller usually control in analog system. The need of maintaining the angular speed of DC-Motors during operation at a specified value becomes recently one of the major concerns of Control-Engineers. Since this type of application is increasingly needed in recent industry. PID-Controllers are one of the techniques that are used to control the angular speed of DC-Motors. This paper shows how PID - Controllers are very powerful in stabilizing DC-Motors speed at a specified value.

2. Separately Excited DC Motor (SEDC) Differential Equations

The DC machine as dynamic system, including the interactions of the electromagnetic and the mechanical effect, is dealing within the following section. The equivalent circuit of the separately exited dc machine can be represented in schematic from as shown in Fig (1).



Figure(1): The equivalent circuit of a SEDC

The electrical equation of a DC motor is derived from the simple motor circuit illustrated in Fig (1). The electrical relation between these variables is given by equations (1- 6) where E_b, the internally motor back emf constant, K_v, is a measure of the voltage per unit speed generated when the rotor is turning. The magnitude and polarity of K_v are functions of the shaft angular velocity, ω_r and direction of rotation respectively. In addition, K_v is the motor torque constant that is a measure of the torque-per-unit-current produced by the motor. The dynamic equation of a motor is given by:

$$V_a = i_a R_a + L_a \frac{di_a}{dt} + E_b \qquad (1)$$

$$E_b = L_{af} i_f \omega_r \qquad (2)$$

$$K_v = L_{af} i_f \qquad (3)$$

$$V_f = i_f R_f + L_f \frac{di_f}{dt} \qquad (4)$$

$$T_e = K_v i_a \qquad (5)$$

$$T_e = J\frac{d\omega_r}{dt} + \beta \omega_r + T_L \qquad (6)$$

V_a : Applied Voltage , i_a : Motor current , E_b : Induced Back Emf Voltage

L_a : Armature Winding Inductance , R_a : Armature Resistance , T_e : Motor Output Torque and ω_r: Motor Output Speed

3. Block Diagram and Transfer Function of SEDC Motor

It is necessary to depict the voltage and torque equations of DC machine in block diagram form when considering the machine as a part of an overall system. Accurately, the equations that we have already derived for the separately excited DC motor, which we will put into, block diagram form. From the block diagrams, we can derive the transfer function of the DC motor, which are used in the design of current and speed controller

4. Time Domain Block Diagram of SEDC Motor

Block diagram, which portray the interconnection of the system equations is used extensively in control system design. we shall work with time-domain equations using the (P) operator to denote differentiation with respect to time ($\frac{d}{dt}$) and the operator ($\mathbf{1/p}$) denote integration. Therefore, we will have no trouble converting the time- domain block diagram , so transfer functions by using the Laplace operator, $\int \mathbf{dt}$ .Arranging the equation of the separately excited DC machine into a block diagram representation is straight forward.

The field and armature voltage equations and the relationship between torque and rotor speed may be combined produces the armature current, torque, field current and motor speed as follows:

$$i_a = (V_a - E_a).\frac{1/R_a}{1+\tau_a p} \quad (7)$$

$$\omega_r = (T_e - T_L).\frac{1}{(Jp+\beta)} \quad (8)$$

$$i_f = v_f .\frac{1/R_f}{1+\tau_f P} \quad (9)$$

Where, $\tau_a = L_a /R_a$, $\tau_f = L_f/R_f$

From equations. (1-9), the time-domain block diagram is obtained as shown in Fig (2).

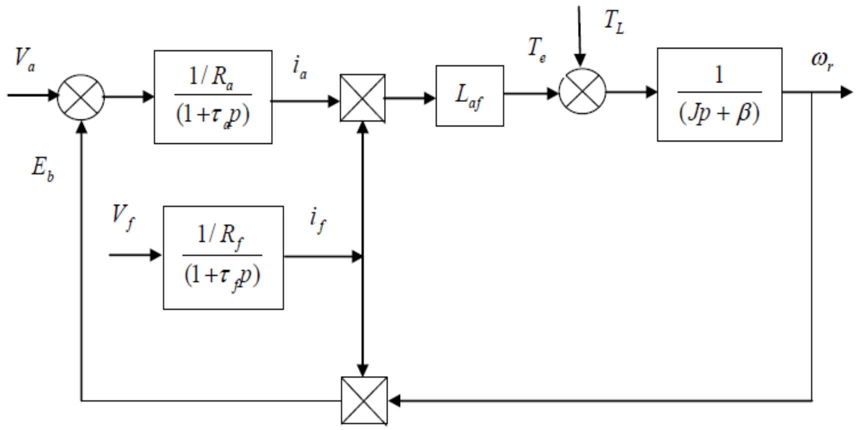


Figure (2): Time Domain Block Diagram of SEDC

5. MATLAB SIMULATIONS, RESULTS AND ANALYSIS

An electrical DC drive is a combination of controller, converter and DC motor. Here chopper is used as a converter. The basic principle behind DC motor speed control is that the output speed of DC motor can be varied by controlling armature voltage keeping field voltage constant for speed below and up to rated speed. The output speed is compared with the reference speed and error signal is then fed to speed controller. If there is a difference in the reference speed and the feedback speed, Controller output will vary. The output of the speed controller is the control voltage that controls the operation duty cycle of converter. The basic block diagram for DC motor speed control is show in fig (3) below:

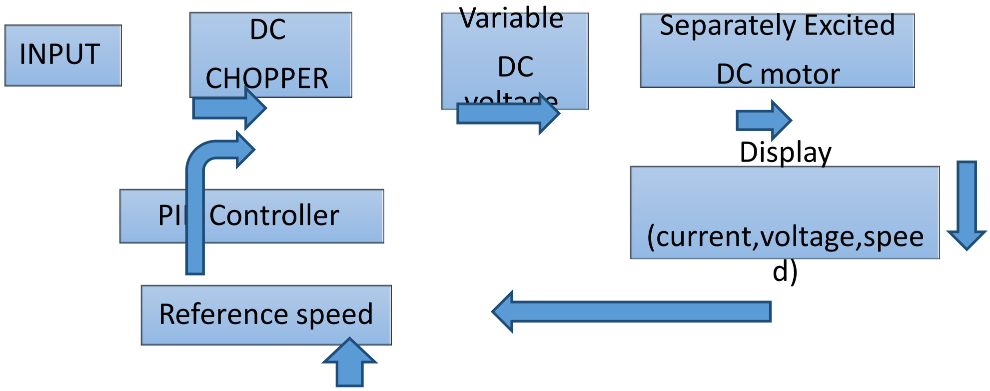


Figure (3): Basic Block Diagram for DC Motor Speed Control

5.1 Modelling of SEDC motor

The equivalent circuit of a SEDC is shown in Fig (1), dependent on the equivalent circuit, the mathematical equations of the motor are obtained using electromechanical energy conversion and torque balance rules.

5.2 Modelling of DC-DC Buck Converter

Modelling for DC-DC buck converter based on state-space average method can be achieved to obtain an accurate mathematical model of the converter. A sate-space averaging methodology is a mainstay of modern control theory and most widely used to model DC-DC converters. The state space averaging method use the state-space description of dynamical systems to derive the small signal averaged equations of PWM switching converters [13].

Figure (4) illustrates the procedures of power stage modelling. The state space dynamics description of each time-invariant system is obtained. These descriptions are then averaged with respect to their duration in the switching period providing an average model in which the time variance is removed, which valid for the entire switching cycle. The resultant averaged model is nonlinear and time-invariant. This model is linearized at the operating point to obtain a small signal model.

The linearization process produces a linear time invariant small-signal model. Finally, the time-domain small signal model is converted into a frequency-domain, or s domain, small-signal model, which provides transfer functions of power stage dynamics. The resulting transfer functions embrace all the standard s-domain analysis techniques and reveal the frequency-domain small-signal dynamics of power stage [39].

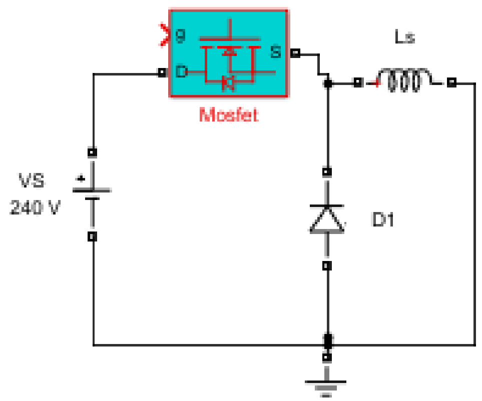


Figure (4): Model of DC-DC Buck Converter

5.3 Modelling of PID Controller

A PID controller is a control loop feedback mechanism (controller) and widely used in industrial control systems. A PID controller calculates the error value of the difference between a measured process variable and a desired set point. The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three term control: the proportional, the integral and derivative values, may be denoted by P, I, & D. Simply put, 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. 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 [14].

PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly. This method is most useful when a mathematical model of the process or control is too complicated or unknown. A simple strategy widely used in industrial control is PID controller. A PID Controller is being designed for a higher order system; Fig (5) shows the Simulink diagram of the PID Controller with unity feedback.

The response of this technique is fast and reliable as it can be seen in fig (6).

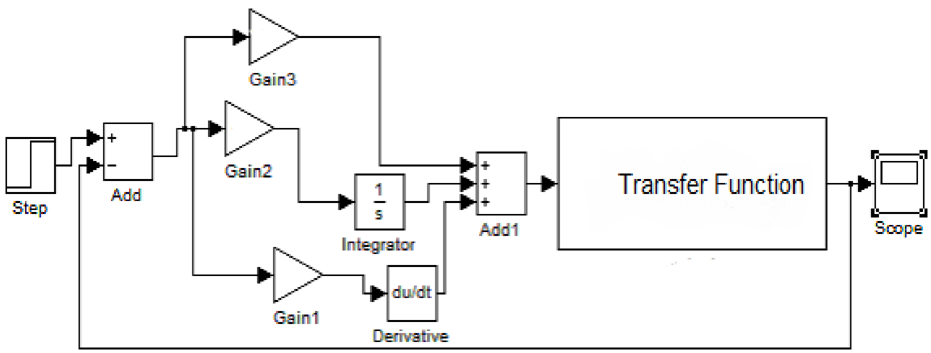


Figure (5): Simulink Diagram of the PID Controller.

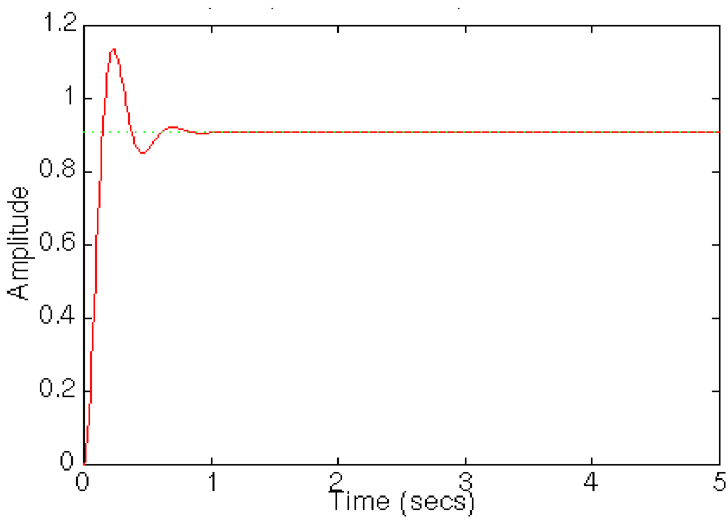


Figure (6): The Step Response of the PID Controller.

5.4 At No Load

In order to effectively understand the SEDC, it is necessary to understand their characteristic curves. For every motor, there is a specific Speed/Voltage curve

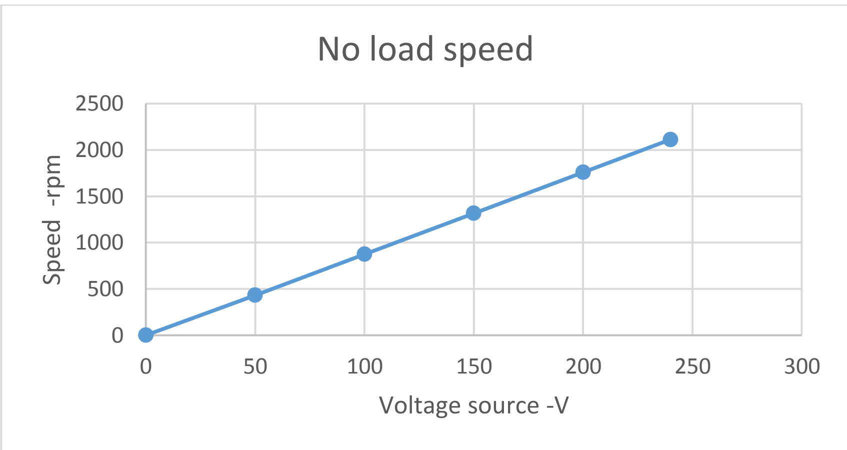


Figure (7): No Load Speed of a SEDC Motor

The graph above shows a speed/voltage curve of the purposed SEDC, Figure (7). It is clear that speed is proportional to the armature voltage of the motor.

5.5 Modelling and control of SEDC motor using MATLAB /SimPowerSystems

Figure (8) shows the speed control circuit of an armature controlled SEDC using chopper circuit, and in Fig. (9) its MATLLAB/SimPowerSystems model, is shown. It consists of a SEDC fed by a DC source through a chopper circuit and a single Mosfet with its control circuit form the chopper circuit. The motor drives a mechanical load characterized by inertia J, friction coefficient B, and load torque TL. The control circuit consists of a speed control loop and a current control loop. A (PID) controlled speed control loop senses the actual speed of the motor and compares it with the reference speed to determine the reference armature current required by the motor. One may note that any variation in the actual speed is a measure of the armature current required by the motor. The current control loop consists of a hysteresis current controller (HCC). The block diagram of a hysteresis current controller is shown in Fig. (10). HCC is used to generate switching patterns required for the chopper circuit by comparing the actual current being drawn by the motor with the reference current. A positive pulse is generated if the actual current is less than reference armature current, whereas a negative pulse is produced if the actual current exceeds reference current. HCC is a method of controlling a power electronic converter so that an output current is generated which follows a reference current waveform. A HCC is implemented with a closed loop control. The difference between the desired current, and the current being injected is used to control the switching of the chopper circuit. When the error reaches an upper limit namely upper hysteresis limit, Mosfet is switched to force the current the current down. On the other hand when the error reaches the lower hysteresis limit, a positive pulse is produced to increase the current. The minimum and maximum values of the error signal are (e-min) and (e-max). The range of the error signal, (e-max) and (e-min), directly controls the amount of ripple in the output current and is called the hysteresis band. Thus the armature current is forced to stay within the hysteresis band determined by the upper and lower hysteresis limits.

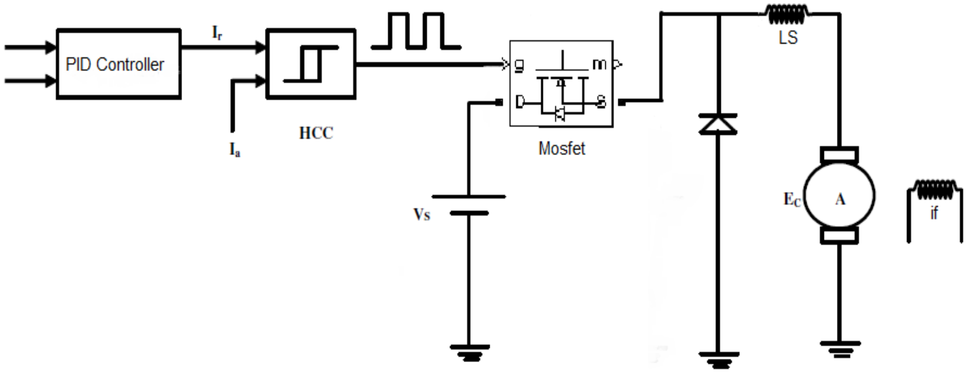


Figure (8): Speed Control Circuit of an Armature Controlled SEDC Motor Using Chopper Circuit

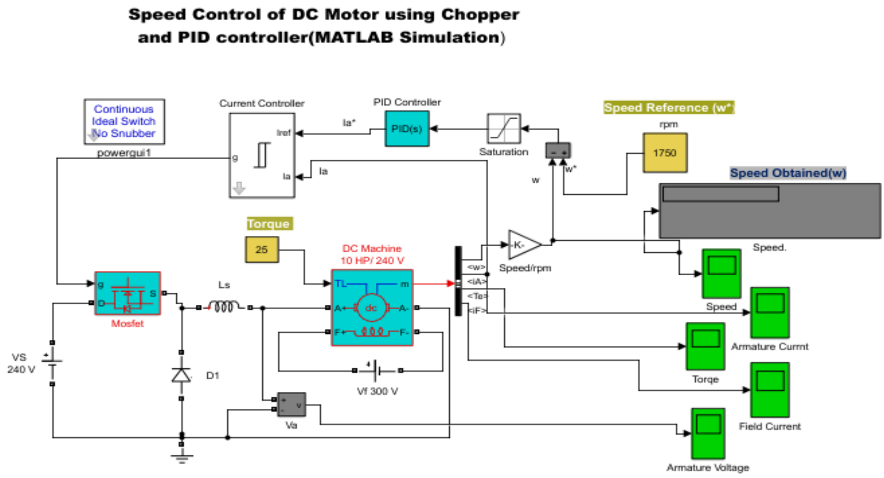


Figure (9): MATLLAB/SimPowerSystems Model

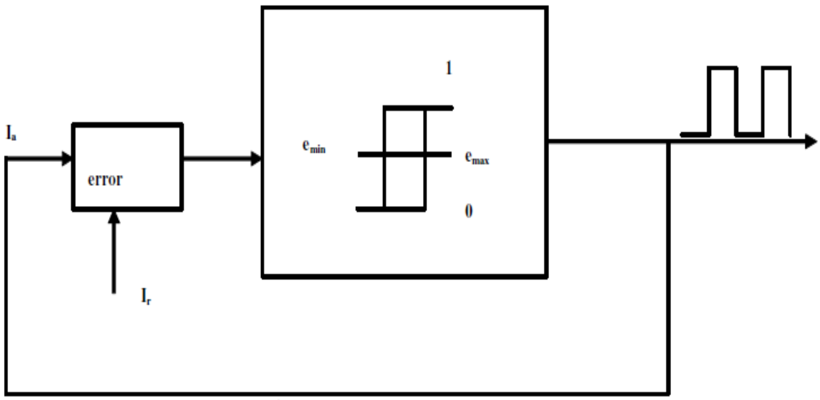


Figure (10): Block Diagram of a Hysteresis Current Controller

5.6 Matlab Simulation Results

The speed control circuit of a SEDM using Simulink is shown in figure (9). In that model the MOSFET is used as a switch for the best performance of speed control, fast switching and low losses. Here 10HP, 240V, 1750 rpm separately excited DC motor and 300V DC supply for field is used; table (1) illustrated the parameters of the used motor.

Table (1):Parameters of SEDC motor

SYMBOL	MAGNITUDE
R_A	1.086Ω
L_A	0.01216H
V_A	240V
J_M	0.04251Kg.m2
B_M	0.003406N.m/rad/sec
T_L	25N.m

The Subsystem simulation model of current controller is illustrated in fig (10). The outputs of the simulation results are shown in figures below in which four DC motor parameters are observed using displays, such as speed of DC motor, as shown in fig(11),output torque is shown in fig(12) , also armature current and field Current are shown in fig(13) and fig(14) respectively.

Table (2) shows the compression between the reference speed and obtained speed at the output in each once and error between them, also this table shows how the values of armature voltage can be changed with respect to changing in speed reference of the DC Motor.

Table (2): Comparing between the Speed Reference and Speed obtained at the output after 5sec

		Speed Reference(w*) rpm	Armature Voltage (Va) volt	Speed Obtained (w) rpm	Error %
A	1	750	180.8	749.86	% 0.018
	2	1000	193.6	999.89	% 0.011
	3	1250	74.76	1249.93	% 0.005
	4	1500	218.3	1499.89	%

					0.007
B	5	1750	231.7	1749.88	% 0.006

Table (2)a: Comparing at Speed of (750 rpm)

Speed Reference(w*) rpm	Armature Voltage (Va) volt	Speed Obtained (w) rpm	Error %
750	180.8	749.86	% 0.018

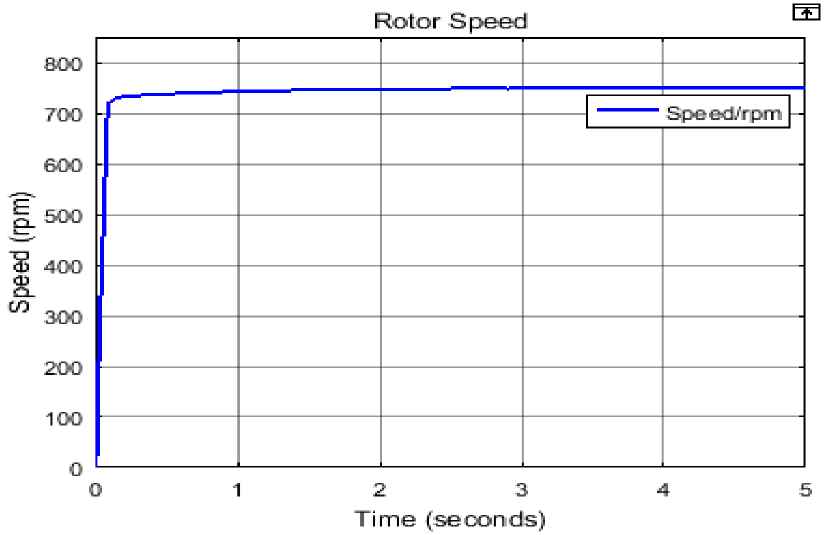


Figure (11): Speed of DC Motor at 750 rpm

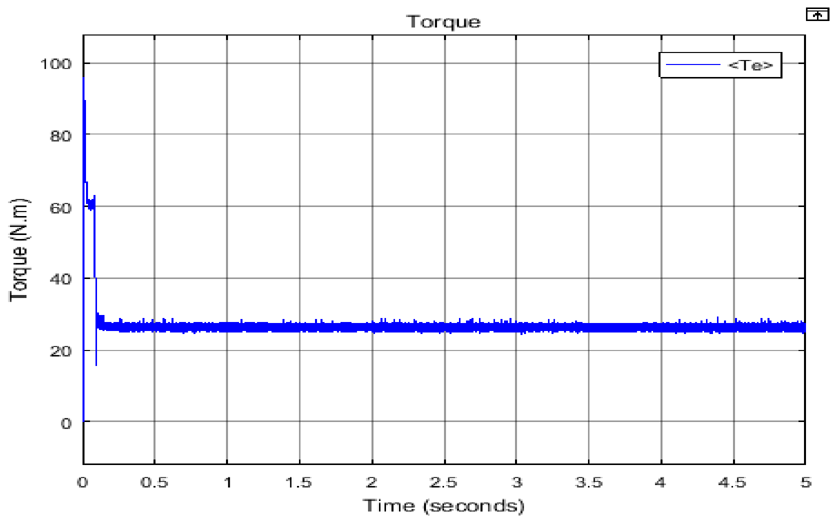


Figure (12): Output Torque of DC Motor at 750 rpm

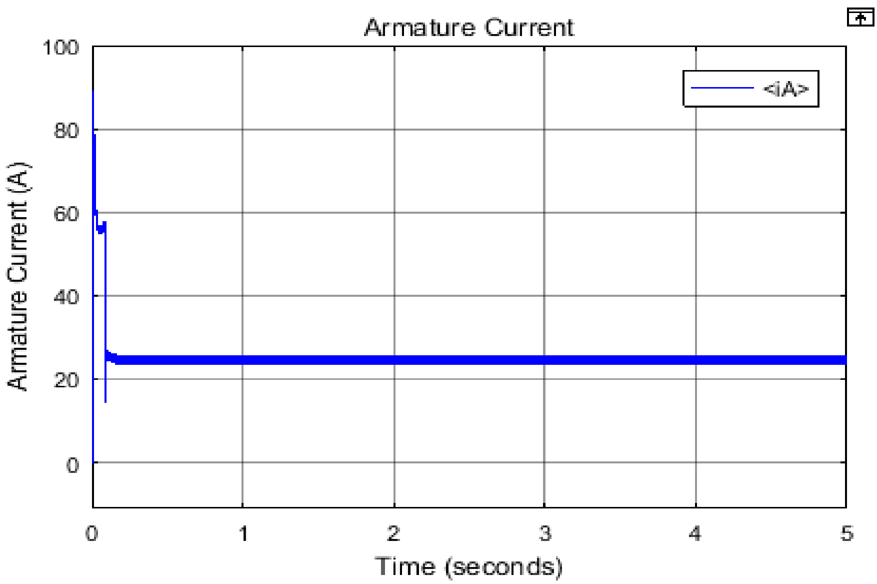


Figure (13): Armature Current of DC Motor at 750 rpm

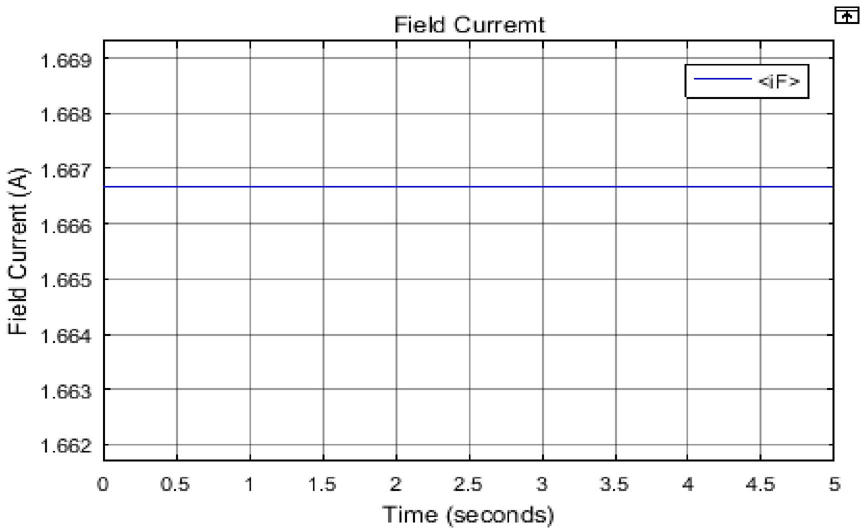


Figure (14): Field Current of DC Motor at 750 rpm

Table (2)b: Comparing at Speed of (1750 rpm)

Speed Reference(w*) rpm	Armature Voltage (Va) volt	Speed Obtained (w) rpm	Error %
1750	231.4	1749.88	0.006%

Simulation results of SEDC shows that the speed of a DC motor has been successfully controlled by using Chopper as a converter and P type controller as a speed and current controller based on the closed loop model of DC motor. Initially a simplified closed loop model for speed control of DC motor is considered and requirement of current controller is studied. Then a generalized modelling of DC motor is done. After that a complete layout of DC drive system is obtained. The MATLAB/SIMULINK model shows good results under below the rated speed during simulation. These results show how fast, the system is responding with good performance. System has reached its steady state before 0.5 seconds.

6. Conclusion

One of the existing challenges in control and instrumentation engineering is the designing of a control system that can respond very fast, with maximum stability, to a dramatic change in the input and to maintain the desired output in the presence of a disturbance. A simple example of a system that requires a highly sensitive control system is the control of the armature speed of a DC motors. DC motors are of specific interest because they can be used in many fields such as robotics. It can also be found in many portable home appliances, automobiles and industrial equipment's. Therefore, at the early stage of learning control and instrumentation engineering, the study of DC motors will be helpful in understanding systems that are more complex. Speed control of SEDC and performance analysis by software simulation has been done. The objective of this project is to describe the principle of DC motor speed control using nonlinear combined control (armature voltage and field current) and proportional integral- derivative (PID) controller for DC motor drives. In the armature control mode, the field voltage is constant and an adjustable voltage is applied to the armature.

The speed of a DC motor has been successfully controlled in this project by using DC Chopper as a converter and A proportional–integral–derivative (PID) as the controller for closed loop speed control system. The steady state operation and its various torque-speeds characteristic of SEDC motor are studied. The results are analayzed and studied accordance with the preceding conditions. Generalized modeling of SEDC is achieved and speed of motor is accomplished using matlab simulation. The model shows good results under all conditions employed during simulation. Here speed control of SEDC motor is done for rated and below rated speed.

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