

# Case of Study for Classical Control Theory Course Using Information and Communication Technologies

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**Abstract**— The objective of this article is to show with a case of study how the Information and Communication Technologies (ICT) can be used to support the process of teaching the relative complex theory of Control. In this case we show how the interactive Matlab/Simulink software represents a valuable tool to visualize graphically a control process. This visualization helps the engineering students to understand the complex concepts of the control theory. To show the ICT advantages and a proposal of how they can be used via Matlab/Simulink a case of study, based on the speed control of a Series DC Motor, is presented. Two approaches, the Ziegler-Nichols and Bode-shape methodologies, and the interpretation of the PID as a one-step-ahead predictor are presented together with a robust analysis based on the Nyquist stability criteria. The Series DC Motor represents an appropriate example because it is non-linear and therefore it is suitable to explain the concepts of linearization, linear dynamics analysis, and the design and implementation of linear robust controllers like the classical PID controller.

**Keywords**—Control Theory, ICT, Linearization, PI controllers, System Analysis, Series DC Motor.

## I. INTRODUCTION

THE development and evolution of the Information and Communication Technologies (ICT) has produced the

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rising of Interactive Multimedia Applications which allows an easy interaction between the user and the computer by means of the various ways the information can be display, that is: texts, images, graphs, sounds, numerical calculations, etc. which, on the other hand, has been very successful and very well accepted in the academia. The integrations of ICT in the Electronic Engineering curricula can be perform in different ways in particular by digital simulations, [1]. The digital simulations have become an excellent tool to improve the comprehension and understanding of the control theory, [2-6]; even more, ICT can be successfully use in the understanding and comprehension of the abstract concepts of pure mathematics, [7]. For instance, in [8] a very interesting case of analysis and design for a flight control system using Matlab/Simulink in a multivariable context is shown. Digital simulations allow the user to experiment using a mathematical model the effects of changing the conditions and parameters in the object of study; also, the user can evaluate the consequences of his decisions and hence to infer how the real process will behave. Therefore, the student takes an active role in the teaching-learning process by recognizing the effects of his own decisions. Also, it can be conclude that digital simulations promote the creativity, individualized learning process and auto evaluation, save time and money and even more it allows learning by discovery.

Matlab/Simulink [9] is one of the most widespread software in the universities becoming an indispensable tool in many teaching-learning processes and research due to the large variety of toolboxes for as many applications. In particular, Simulink is a tool for modeling, simulating and analyzing multidomain dynamic systems in a graphical context. Matlab/Simulink is now day a standard tool within the community of Control and it is widely used in many undergraduate and postgraduate courses. [9-12]. Moreover, due to its graphic context, programing with Simulink is an easy task because many blocks or subroutines can be interconnected in a very simple manner.

In Control laboratories the design and real time implementation of classical and modern control systems has become a very simple assignment thanks to Matlab-Simulink because of its friendly interface, [13]. This allows the user to concentrate in the analysis and design of the control system itself. These characteristics has been widely exploited by the authors developing and controlling many processes, descriptive of many industrial processes, which are very simple to operate

avoiding the excessive use of wires and, [14-16]. Based on these experiences, in this paper the authors present, by means of a case of study, an alternative idea to present to the students the analysis, design and implementation of a control system.

## II. CASE OF STUDY: SERIES DC MOTOR DYNAMICS

The series DC motor is a kind of electric DC motor in which the field coil is connected in series with the armature. In order to design a speed controller for this kind of motor it is necessary to develop a model including its most important dynamic characteristics. A model which complies with these requirements is given by, [17]:

$$\begin{aligned} L \frac{di}{dt} &= -Ri - K_m L_f i w + V \\ J \frac{dw}{dt} &= K_m L_f i^2 - Dw - \tau_L \end{aligned} \quad (1)$$

where

- $i(t)$ : Armature current
- $V(t)$ : Input Voltage
- $w(t)$ : Rotor angular velocity
- $\tau_L$ : Torque Load
- $R$ : Armature resistance,  $R=7.2 \text{ ahms}$
- $L$ : Armature inductance  $L=0.091 \text{ h}$
- $J$ : Inertia  $J=0.0007046 \text{ Kg-m}^2$
- $D$ : Friction Coefficient  $D=0.0004 \text{ N-m-sec/rad}$
- $K_m L_f$ : Motor Constant  $K_m L_f=K_T=0.1236 \text{ N-m/Wb-A}$

It is important to note that by construction this kind of motors can rotate only in one sense, [17]. If the control requirements include the change of turn sense which is a normal condition for actuators it is necessary to design a power inverter capable of commuting the polarization; that is, capable of inverting the current sense in the fields coil.

To simplify the notation the following constants and variables are defined:

$$\begin{aligned} a_1 &= \frac{K_m L_f}{J} & b_1 &= \frac{R}{L} & x_1 &= w \\ a_2 &= \frac{D}{J} & b_2 &= \frac{K_m L_f}{L} & x_2 &= i \\ a_3 &= \frac{1}{J} \tau_L & b_3 &= \frac{1}{L} \end{aligned} \quad (2)$$

Therefore, the system described by the (1) results in:

$$\begin{aligned} \dot{x}_1 &= a_1 x_2^2 - a_2 x_1 - a_3 \tau_L \\ \dot{x}_2 &= -b_1 x_2 - b_2 x_1 x_2 + b_3 V \end{aligned} \quad (3)$$

## III. LINEAR APPROXIMATION OF THE SERIES DC MOTOR

The system of equation (3) can be expressed in the state space representation given by:

$$\dot{x} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} a_1 x_2^2 - a_2 x_1 - a_3 \tau_L \\ -b_1 x_2 - b_2 x_1 x_2 + b_3 V \end{bmatrix} = f(x, u) \quad (4)$$

It is well known that it is possible to obtain a linear approximation around an equilibrium point of (4) by cutting out the higher degree terms of its Taylor series expansion, [18]. That is, the system can be described in the linear state space representation given by:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx \end{aligned} \quad (5)$$

where

$$\begin{aligned} A &= \frac{\delta f(x, u)}{\delta x} \begin{bmatrix} -a_2 & 2a_1 x_2^0 \\ -b_2 x_2^0 & -(b_1 + b_2 x_2^0) \end{bmatrix} \\ B &= \frac{\delta f(x, u)}{\delta u} \begin{bmatrix} -a_3 & 0 \\ 0 & b_3 \end{bmatrix} \\ C &= [1 \quad 0] \end{aligned} \quad (6)$$

and

$$\begin{aligned} u &= \begin{bmatrix} \tau_L \\ V \end{bmatrix} \\ y &= w(t) \end{aligned} \quad (7)$$

Evaluated in the equilibrium point:

$$x_1 = x_1^0; \quad x_2 = x_2^0$$

where

$$x_2^0 = \sqrt{\frac{a_2 x_1^0 + a_3 \tau_L}{a_1}} \quad (8)$$

and

$$V = \frac{x_2^0 (b_1 + b_2 x_1^0)}{b_3} \quad (9)$$

If the load torque is assumed zero  $\tau_L = 0$

$$x_2^0 = \sqrt{\frac{a_2 x_1^0}{a_1}} \quad (10)$$

$$V = \frac{x_2^0(b_1 + b_2x_1^0)}{b_3} \quad (11)$$

and matrix B reduces to:

$$B = \begin{bmatrix} 0 \\ b_3 \end{bmatrix} \quad (12)$$

This results in a model with only one input assuming the torque load as a perturbation.

The transfer function associated to the linear state representation (5) relating the angular velocity  $\omega(t)$  with the input voltage  $V(t)$  is given by, [18]:

$$\frac{W(s)}{V(s)} = G(s) = C(sI - A)^{-1}B \quad (13)$$

With the system given by (13) it is possible to design and implement controlles based on the classical control theory such as P, PI and PID controlles. On the other hand, it is convenient, for simplicity, to use the model without torque load because normally it is assumed as a perturbation. This implies that the controller must be robust to torque load perturbations.

The transfer function (13) can be calculated using the next Matlab program and parameters of a real series DC motor for any equilibrium point:

1. KmLf=0.1236;
2. R=7.2;
3. D=0.0004;
4. L=0.0917;
5. J=0.0007064;
6. a1=KmLf/J;
7. a2=D/J;
8. a3=1/J;
9. b1=R/L;
10. b2=KmLf/L;
11. b3=1/L;
12. %Case Tl=0
13. x10=190;
14. x20=(a2\*x10/a1)^(1/2);
15. V=(x20\*b1+b2\*x20\*x10)/b3;
16. A=[-a2,2\*a1\*x20;-b2\*x20,-(1+b2\*x10)];
17. B=[0; b3];
18. C=[1, 0];
19. D=0;
20. [num,den]=ss2tf(A,B,C,D)
21. G=tf(num,den)
22. roots(den)

The motor parameters are defined in the instructions 1-11; the equilibrium point, given by  $x_{10}=190$ rad/seg,  $x_{20}=0.7841$ A, and  $V=24.0607$ volts are defined in the instructions 13-15. The linear state space representation is calculated in the instructions

16-19 and the transfer function in the instructions 20-21, resulting in:

$$\frac{W(s)}{V(s)} = \frac{2992.4437}{s^2 + 335.1791s + 479.5441} \quad (14)$$

The poles of the transfer function (14) calculated in instruction 22 are -333.7423 and -1.4367. Therefore the system is stable and over damped.

#### IV. PID CONTROLLER INTERPRETATION AND PI DESIGNS

The PID (Proportional-Integral-Derivative) controller is given by, [15]:

$$u(t) = K_p \left[ e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d e'(t) \right] \quad (15)$$

In the Laplace domain:

$$U(s) = K_p \left[ 1 + \frac{1}{T_i s} + T_d s \right] E(s) \quad (16)$$

The PID controller is still the most popular controller capable of dealing with many industrial problems. It has many interpretations and design approaches. For instance it is a *one-step-ahead predictor*; that is: consider the first derivative of the PID given by:

$$u'(t) = K_p \left[ T_d e''(t) + e'(t) + \frac{1}{T_i} e(t) \right] \quad (17)$$

Note that equations (15) and (17) have exactly the same solution except for a constant of integration. On the other hand, the Taylor series expansion of  $e(t+t_0)$  is given by:

$$e(t+t_0) = e(t) + e'(t)(t+t_0) + \frac{e''(t)}{2!}(t+t_0)^2 + \dots \quad (18)$$

That is, equation (17) can be interpreted as the Taylor series expansion, up to the second degree term, of the error signal  $e(t)$ . This means that the design of  $K_p$ ,  $T_i$  and  $T_d$  should be carried out as a way to obtain a good prediction of  $e(t+t_0)$ .

This interpretation results obvious if we have a look at the Bode diagrams of a typical PID, shown in figure 1, from where it is clear that the PID controller has a lead phase compensator. Another way to see this characteristic is that the PIDs' transfer function is non-causal with two zeros and one pole as depicted in the following equation:

$$U(s) = K_p \left[ \frac{T_d s^2 + s + \frac{1}{T_i}}{s} \right] E(s) \quad (19)$$

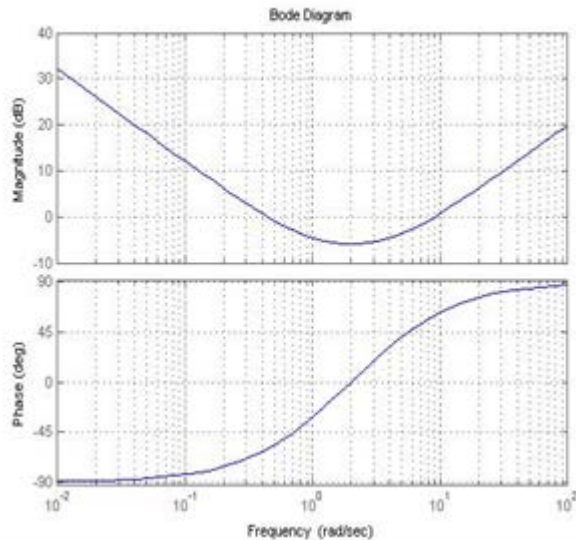


Fig. 1 PID Bode diagram

### A. Bode Shape PI Design

From the linearized model (14) it is possible to distinguish the two typical dynamics of a DC motor:  $(s+1.467)$  representing the slow dynamic of the mechanical subsystem and  $(s+333.7)$  which represents the fast dynamic of the electrical subsystem.

The closed loop control system of the series DC motor with a PI controller is shown in figure (2).

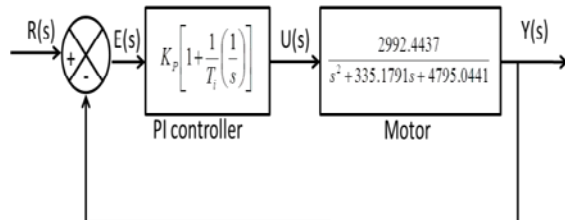


Fig. 2 Closed loop control system

Based on the classical method of Bode-Shape the design of the speed PI controller is given by:

$$G_{PI}(s) = \frac{s+1.43}{s} \quad (20)$$

The Bode diagrams of the open loop transfer function  $G_{PI}(s)G(s)$  are shown in figure (3). From these diagrams is possible to see that the phase and gain margins are  $M_f=88.5^\circ$  y  $M_g=\infty$  dB's, respectively, and a bandwidth  $\omega_B=8.96$ rad/sec. Therefore, the control system is robust around the equilibrium point.

It must be recall that the gain and phase margins as a measure of robustness comes from the Nyquist stability criteria in which the relative stability -the capability of the control system to maintain stability and performance against noise and perturbations- depends on how far is the Nyquist plot of its open loop transfer function from the point  $(-1,0)$ . In figure (4) the Nyquist plot of  $G_{PI}(s)G(s)$  is shown. From this figure it is

clear that the Nyquist plot of  $G_{PI}(s)G(s)$  is far from the point  $(-1, 0)$  at all frequencies.

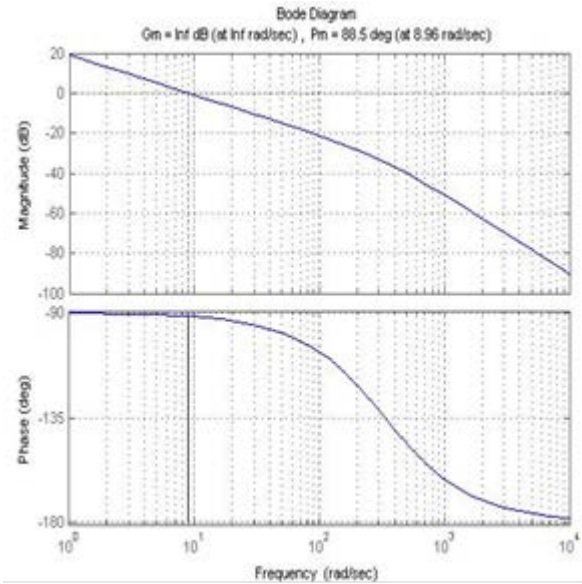


Fig. 3 Open loop Bode diagrams with controller  $G_{PI}(s)$

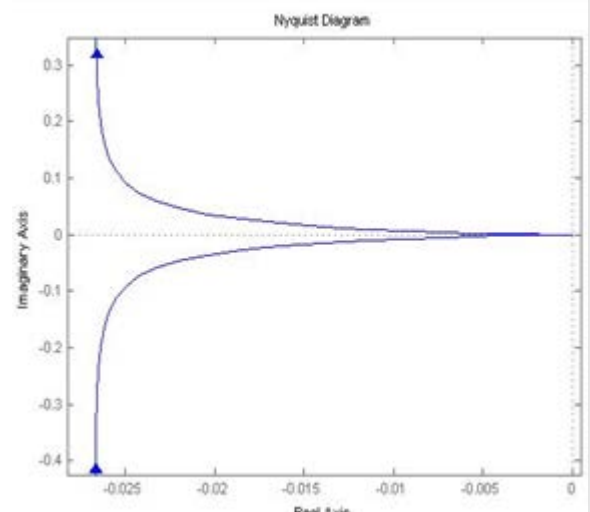


Fig. 4  $G_{PI}(s)G(s)$  Nyquist plot

The relative high phase margin  $M_f=88.5^\circ$  explains why a full PID controller is not necessary as no additional phase lead is required.

### B. Ziegler-Nichols PI Design

The Ziegler-Nichols approach to the design of P, PI and PID controllers, [18], has been one of the most widely methodologies implemented in the industry. This is due to its simplicity and effectiveness in the design of PID controllers for many industrial processes. There are two Ziegler-Nichols methods: The first method, also known as *Step Response Method*, and the second method known as the *Limit Gain Method*. The first method is indicated to stable and over damped plants meanwhile the second method is suitable to stable and under damped plants.

In the particular case of the Series DC motor it is clear that the system is stable and over damped; therefore, the first

method of Ziegler-Nichols is the appropriate to the design of a PI controller. This method is based on the approximation of the process by a first order transfer function with a constant time  $\tau=l/m$ , delay time  $L$  and a gain  $K$ .

$$G(s) \approx \frac{Ke^{-Ls}}{\tau s + 1} \quad (21)$$

The step response of the series DC motor, together with its tangent line with a maximum slope  $m=8.76$  is shown in figure (5).

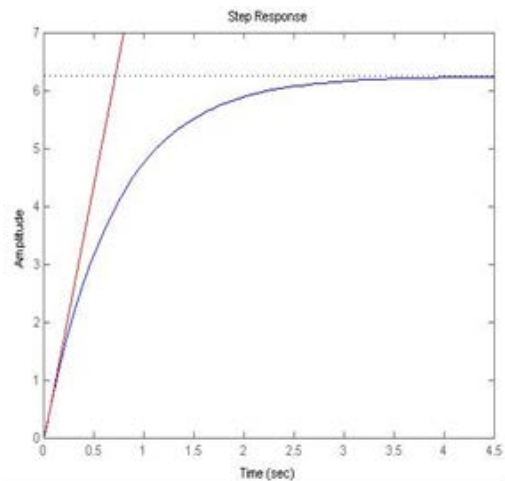


Fig. 5 Step response of the Series DC motor

A zoom of figure (5) is shown in figure (6) where the value of  $L=0.0027$ .

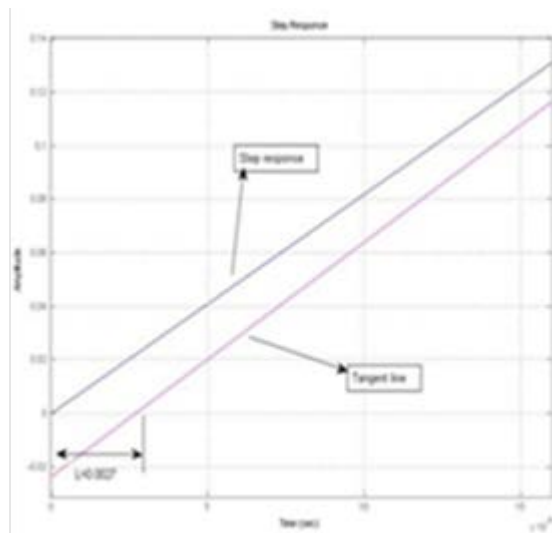


Fig. 6 Zoom of step response of the Series DC motor  
Following de Ziegler-Nichols rules the PI gains are given by:

$$K_p = \frac{0.9}{ml} = 38.05 \quad (22)$$

$$T_i = \frac{L}{0.3} = 0.009$$

Therefore, the PI controller based on the first method of Ziegler-Nichols results in:

$$G_{PI-ZN}(s) = \frac{38.05s + 4227.7}{s} \quad (23)$$

The  $G_{PI-ZN}(s)G(s)$  open loop Bode diagrams are shown in figure (7). The resulting phase and gain margins are  $M_f=28.6^\circ$  y  $M_g=\infty$  dB's, respectively, with a bandwidth of  $\omega_B=281$  rad/sec.

Therefore, the resulting control system can be assumed no robust because of the small phase margin. Nonetheless, it must be noted that the Ziegler-Nichols methodologies recommend performing a manual adjustment in order to fulfill the objectives for performance and robustness. It is obvious that by reducing the gain  $K_p$  and increasing  $T_i$  the design will fulfill the performance and robustness requirements. This will reduce the bandwidth  $\omega_B$  and locate the PI's zero at a much lower frequency. It must be noted that by doing this the Zigler-Nichols PI controller will tend to the PI controller designed via Bode-Shape.

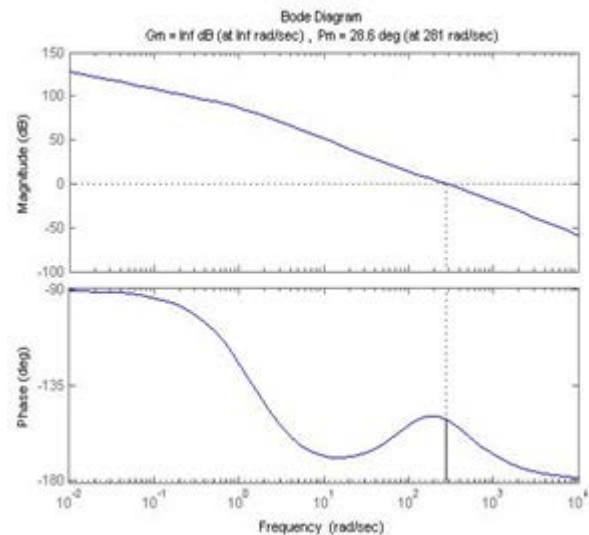


Fig. 7 Open loop Bode diagrams with controller  $G_{PI-ZN}(s)$

## V. LINEAR AND NONLINEAR SIMULATIONS

In this section the Simulink programs will be presented in order to perform the simulations of the linear and nonlinear model of the series DC motor in closed loop with the PI controller (20). That is, PI controller designed using Bode-Shape.

### A. Linear Simulation

In figure (8) the Simulink program of the closed loop control system with the linear approximation (14) of the motor is shown. The response of the angular velocity  $\omega(t)$ , shown in figure (9), shows that it reaches the objective of  $190$  rad/sec. These plots are generated using the Matlab instruction `plot(t,w)` together with `grid`.

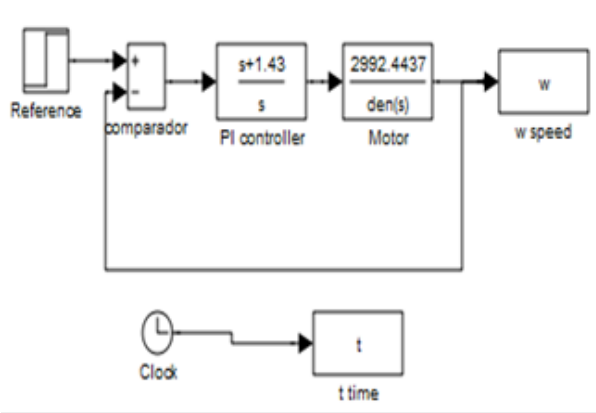


Fig. 8 Simulink program of the linear closed loop control system

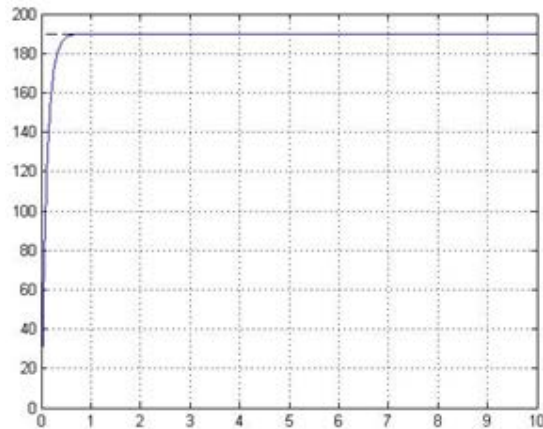


Fig. 9 Rotor speed  $\omega(t)$

The graphs in figures (11) and (12) show the responses of the rotors angular velocity  $\omega(t)$  and the current  $i(t)$ , respectively. From these figures it is possible to see that when the input voltage  $V(t)=24.0607\text{volts}$ , calculated in (9), and as defined for the equilibrium point the angular velocity of the rotor is  $\omega(t)=190\text{rad/sec}$ . Also, in figure (12), the current  $i(t)$  reaches the value calculated in (8).

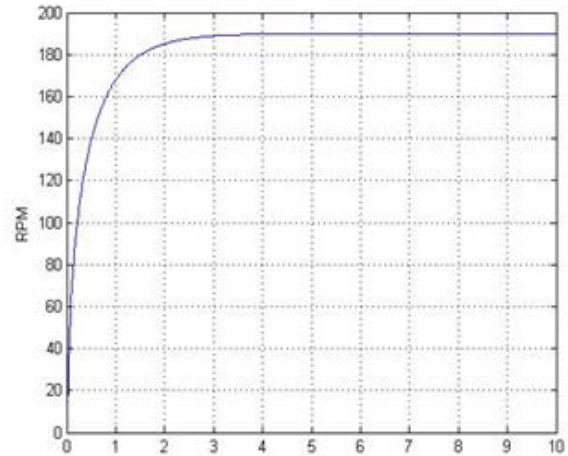


Fig. 11 Rotors velocity

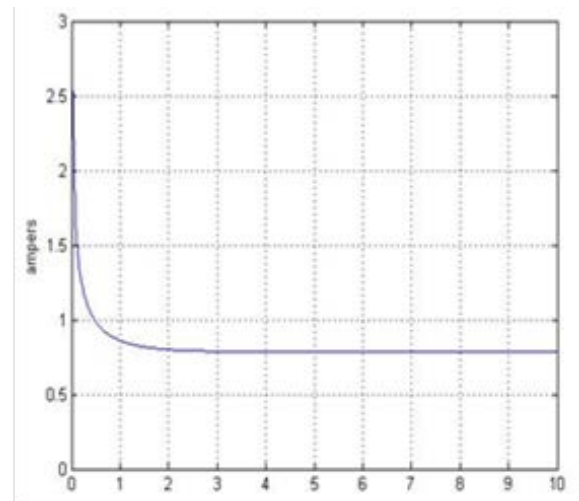


Fig. 12 Motors Current

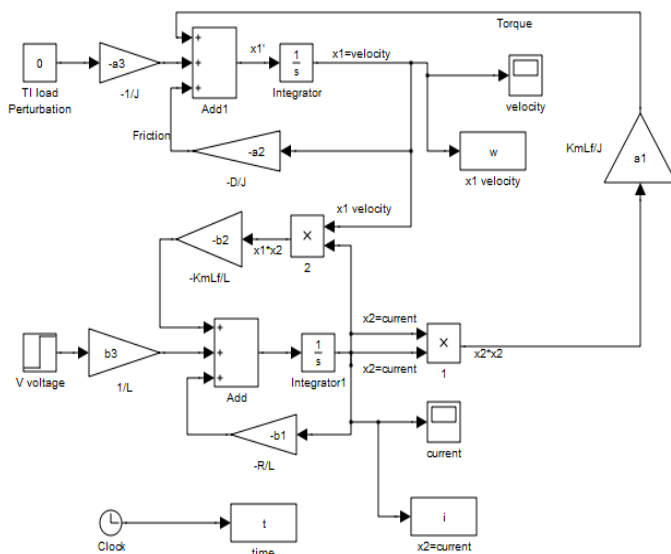


Fig. 10 Simulink program of the nonlinear model of the series DC motor

### B. Nonlinear Simulation

In figure (10), the Simulink program of the nonlinear model of the series DC motor (1) is shown. The parameters  $a_1$ ,  $a_2$ ,  $a_3$ ,  $b_1$ ,  $b_2$  y  $b_3$  are loaded automatically by the Simulink program once the Matlab program of Section III has been executed.

To validate the PI controller of (20) it was implemented together with the nonlinear model of the motor; that is, the nonlinear simulation of the control system. Figure (13) shows the Simulink program of the nonlinear simulation of the control system. From this figure it is possible to see that the nonlinear model of the motor is introduced as a subroutine or subsystem program shown in figure (14). It must be noted that this subroutine has two inputs: The input voltage  $V(t)$  and the torque load  $\tau_L$  and two outputs: the rotor velocity  $\omega(t)$  and the current  $i(t)$ .

In the program depicted in figure (14) the speed reference was changed making use of two *step* instructions, the first one with *step time*=0 and *final value*=190 and the second one with *step time*=10 y *final value*=-10. This creates a step change of 10rad/sec in the reference signal as shown in figure (15). Also, the load torque was changed, as a perturbation, following the

same strategy: a *step* instruction with *step time*=15 y *final value*=1. This introduces a perturbation in the torque load at 15sec. The student can change these parameters to observe their effects in the motor responses.

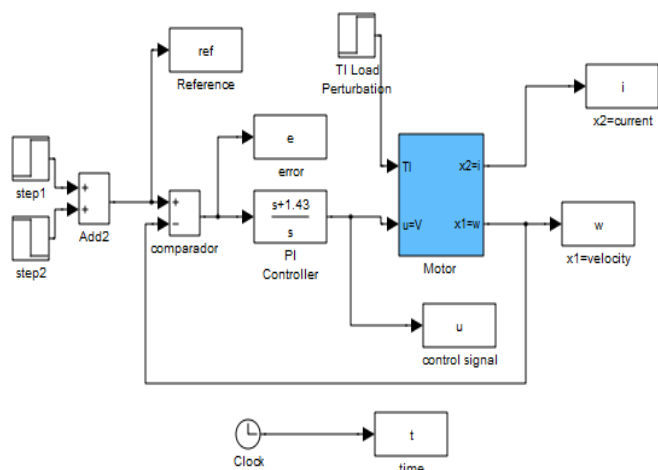


Fig. 13 Nonlinear closed loop control system

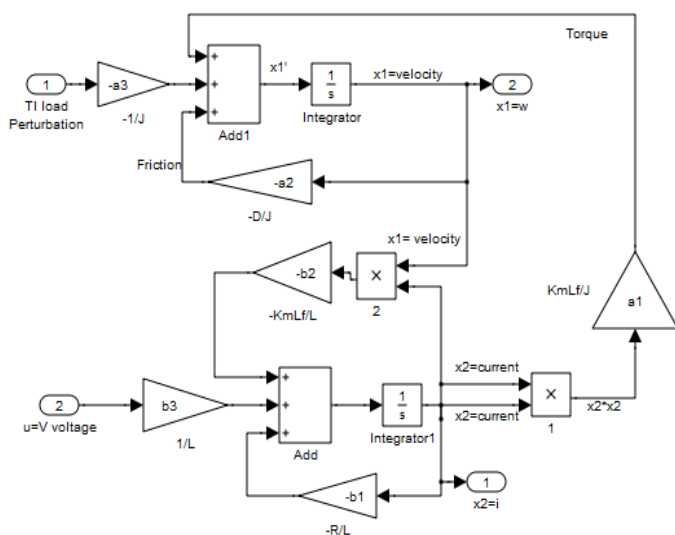


Fig. 14 Motors nonlinear model subsystem (subroutine)

In figures (15), (16) and (17) the rotors velocity  $\omega(t)$ , the current  $i(t)$  and the input voltage  $V(t)$  are shown respectively. From these figures it is possible to see that the linear PI controller satisfies all the specifications: stability, performance and robustness. Even more, it is shown that it is robust to variations in the torque load.

Finally, it is also recommended, for any control system, to perform an assessment against parametric perturbation or uncertainty. In figure (18) the rotors speed response of the nonlinear simulation assuming a 100% perturbation on the armature resistance  $R$  is shown. From this figure it is possible to see that, as anticipated by the resulting phase and gain margins, the control system is robust to one of the most common parametric perturbation of the electric motors with no significant differences compared to that without parametric perturbation of figure (15).

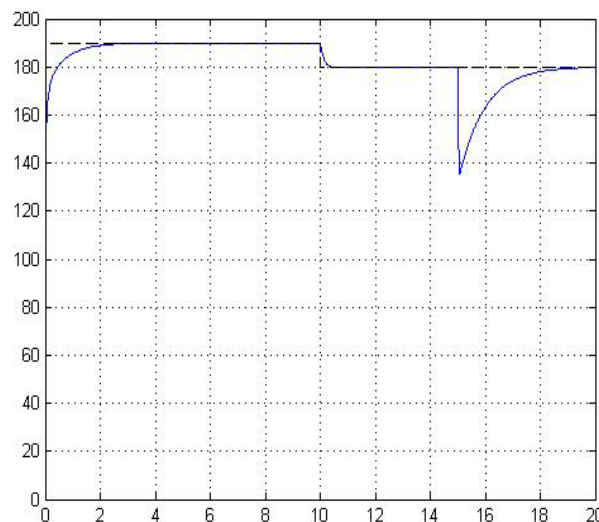


Fig. 15 Rotors velocity and Reference

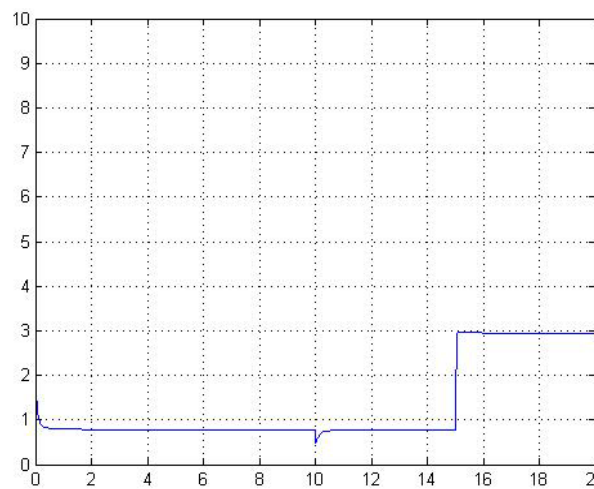


Fig. 16 Current

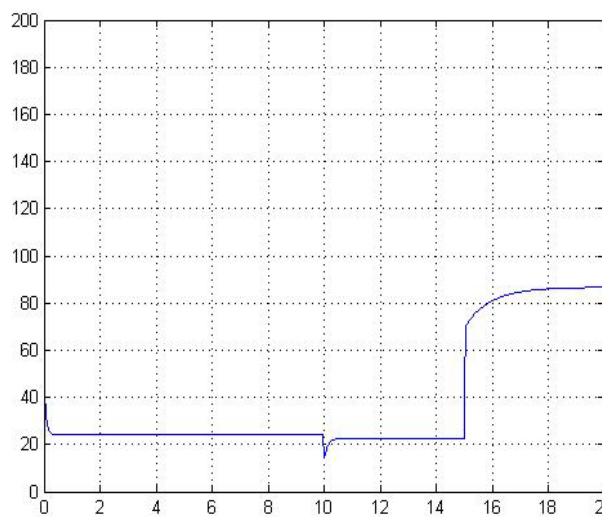


Fig. 17 Control signal (voltage)

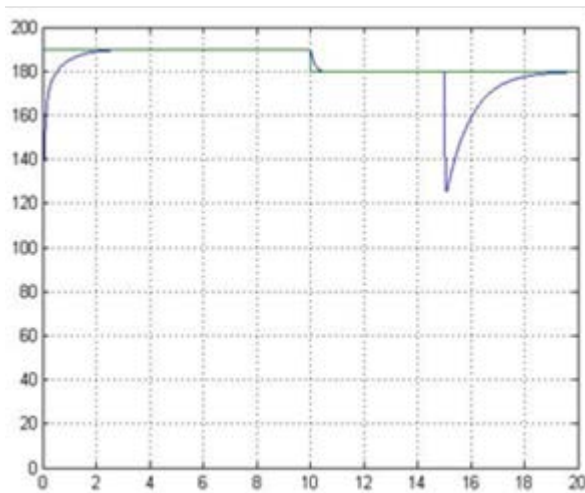


Fig. 18 Rotors velocity and Reference with parametric perturbation

To complement this kind of experiences, the authors recommend that it is also important that the students should implement this control system in a real time context. This can be done using a data acquisition board together with the Simulink Real Time tool box or, as recommended by [19], Labview can be an additional option not only for simulation purposes but for real time implementation objectives. Figure (18) shows the photograph of a series DC motor to be used for real time the implementation of the proposal hereby presented. This motor has the following characteristics:

- Nominal Voltage = 110Volts
- Nominal Current = 0.920Amp
- Nominal velocity = 24000 RPM at 110Volts
- Power=7/8hp
- Load\_mass=0.922kg
- Load\_radio=38mm
- Load\_wide=24mm
- Encoder= 1024 ppr

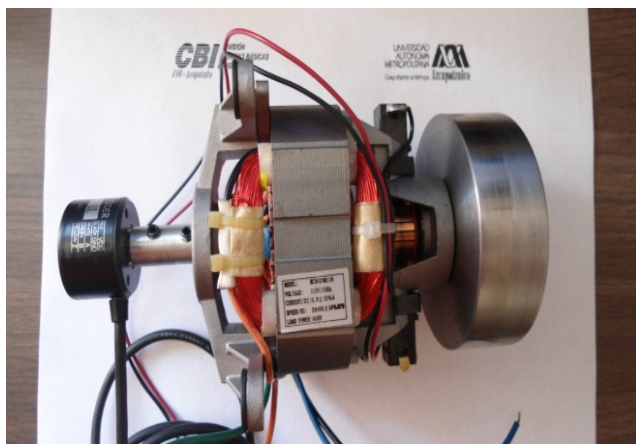


Fig. 19 Series DC Motor

## VI. CONCLUSIONS

In this paper, following the standard methodology, that is, linearization, linear analysis and design, and validation using

nonlinear models, the design of linear controllers using ICT is presented. It shows how ICT can be exploited in the learning-teaching process of Control theory courses. Throughout the paper it is shown, step by step, with an easy but practical case of study how Matlab/Simulink can be used to simulate a control system and experiment and assess its performance and robustness. The case of study is the speed control of a series DC motor using a PI controller. The interpretation of the PID controller as a one-step-ahead predictor together with the classical PID design methodologies of Bode Shape and Ziegler-Nichols are shown. It should be noted that this kind of motors represent a challenging problem for the nonlinear control community due to its ill condition of no well-defined relative degree. Following the results presented here the real time implementation will be carried out using the Real Time toolboxes provided by Matlab-Simulink

## REFERENCES

- [1] G. Petropol Serb, I. Petropol Serb, A. Campeanu, A. Petrisor and S. Degeratu, "Virtual Laboratory for Study of Synchronous Machine Parameters", *WSEAS Transactions on Advanced in Engineering Education*. Issue 1, Vol. 6, ISSN:1790-1979, pp. 1-10, January 2010.
- [2] K. Zenger, "Control engineering, system theory and mathematics: the teacher's challenge", *European Journal of Engineering Education*, Volume 32, Issue 6 December, pages 687 – 694, 2007.
- [3] R. Morales-Menendez, Tomás López, R. Ramírez-Mendoza and Luis E. Garza, "Drag and Drop Graphical user Interface for Process Control Education", presented at the 2008 ASSE (American Society for Engineering Education) Annual Conference & Exposition, June 22-25, Pittsburgh, PA, USA, 2008.
- [4] J. Yao and Loren Limberis, "A Project-Driven approach to Teaching controls in General Engineering Program", presented at the 2008 ASSE (American Society for Engineering Education) Annual Conference & Exposition, June 22-25, Pittsburgh, PA, USA, 2008.
- [5] S. Scott Moor and P. Piergiiovanni, "Multi-Modal Process Control Education: Experiment Kits & Simulation in the Classroom", presented at the 2007 ASEE Annual Conference & Exposition, June 24-27, Honolulu, Hawaii, USA, 2007..
- [6] Simulated versus Hardware Laboratories for Control Education: A Critical Appraisal, Proceedings of the 17th World Congress of the International Federation of Automatic Control, Seoul, Korea, July 6-11, pp. 8129-8134, 2008.
- [7] Ana Júlia Viamonte, "The Computer in the Mathematics Teaching", *WSEAS Transactions on Advanced in Engineering Education*. Issue 3, Vol. 7, ISSN: 1790-1979, pp. 63-72, March 2010J.
- [8] Antonios S. Andreatos and Anastasios D. Zagorianos, "ACTA Tools as an integrated Teaching Assistant for the Design of Automatic Flight Control Systems", *WSEAS Transactions on Advanced in Engineering Education*. Issue 3, Vol. 7, ISSN: 1790-1979, pp. 172-179, May 2010.
- [9] Matlab the MathWorks Inc., [Online]. Available: <http://www.mathworks.com>
- [10] Liu Lina, "Application study of modern control theory course teaching by using MATLAB", presented at the 8th International Conference on Information Science and Digital Content Technology (ICIDT), Zibo, China, June 2012, pp. 712 – 717.
- [11] J. M. Ramirez-Cortes, V. Alarcon-Aquino, P. Gomez-Gil, A. Diaz-Mendez, M. Ibarra-Bonilla, I. Garcia-Enriquez "Interactive educational tool for compensators design in MATLAB® using frequency response analysis" *Comput. Appl. Eng. Educ.*, Wiley Periodicals, 2012.
- [12] I. I. Siller-Alcalá, R. Alcántara-Ramírez, J. Jaimes-Ponce, and J. P. Vaca-Pliego. "How to link the theory and practice of control engineering: Practices in real time and simulation". *International Journal of Education and Information Technologies*. Issue 2, Volume 1, WSEAS, 2007.
- [13] I.I. Siller-Alcala, A. Ferreyra-Ramírez, J. Jaimes-Ponce and R. Alcántara-Ramirez, Some properties of Nonlinear Continuous Time



- Generalized Predictive Control, Proc. Presented at the 12th WSEAS International Conference on Mathematical and Computational Methods in Science and Engineering, 2010, pp. 291-296.
- [14] J. J. Rubio Ávila, R. Alcántara-Ramírez, J. Jaimes-Ponce, and I. I. Siller-Alcalá, "Mechanics Design, construction, and control of a novel tower crane". *International Journal of Mathematics and computers simulation*. Issue 2, Volume 1, 2007
- [15] J. J. Rubio Ávila, R. Alcántara-Ramírez, J. Jaimes-Ponce, and I. I. Siller-Alcalá, "Design of a low cost electronic control system for an articulated robot arm". *International Journal of Mechanics*. Issue 2, Volume 1, 2007.
- [16] J. Jaimes-Ponce, R. Alcántara-ramírez, I. I. Siller-alcalá, I. Ramírez-alpízar, N. Nájera-Ramos. "Design, Development and Control of a Water Tank System", *WSEAS Transactions on Advances in Engineering Education*, Vol. 3, Issue 8, pages 739-745, 2006.
- [17] S. Mehta and J. Chiasson, "Nonlinear Control of Series DC Motor: Theory and Experiment", *IEEE Trans. On Industrial Electronics*, Vol.45, No.1 1998, pp. 134-141.
- [18] Ogata Katsuhiko, "Modern Control Engineering", 5<sup>th</sup> Edition, Pearson Prentice, 2009.
- [19] R. A. Jabbar Khan, A. Mohammed, M Junaid, M. A. Masood and A. Iftkhar, "LabVIEW based Electrical Machines Laboratory for Engineering Education", *WSEAS Transactions on Advanced in Engineering Education*. Issue 5, Vol. 7, ISSN: 1790-1979, pp. 161-171, May 2010.

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