# “Hands-on” Electronic Simulators for Electric Drive Systems

**Robert Beloiu**

University of Pitesti,
Targu din Vale, 110040, ROMANIA
E-mail: robert.beloiu[at]upit.ro; robertbeloiu[at]gmail.com

**Abstract**

*In the last years, there is a greater interest in using computers in education, and in particular, in engineering education. Software programs have a great impact on studying many physical phenomena that otherwise could be described only using very complex mathematical algorithms. Furthermore, by computer simulation it can be studied the behavior of many engineering systems before its launching in production. However, the focus many times exclusively could be a handicap for the future engineers from a different perspective: lack of real measurement and future data manipulation and interpretation. At the same time, experimental stands could be often very expensive for many university laboratories. In this article, the author presents a methodology that could be a compromise between the use of software dedicated programs and of really electrical systems. The use of electronic simulators releases the university laboratory of expensive acquisitions and does not put a very large gap between practice and theoretical concepts. Based on the block system diagram of a real system, it is constructed the electronic simulator using basic Operational Amplifier structures' circuits. The result is an electronic system simulator.*

**Keywords**: Computer simulation, Electronic simulator, System simulation, Control System Theory, Electric motor

## 1 Introduction

In recent years, there is a greater current in developing the virtual education as much as possible due to many advantages: easy development, distribution and upgrade [Martin-Villalba et al., 2012]. Another advantage is the possibility of allowing people to be involved in lifelong learning educational programs [Severino et al., 2011]. The virtual simulators are used in several teaching programs of different specialties: engineering, physical sciences, social sciences, etc. [Temiz and Akuner, 2009][Kong et al., 2009][Barrios et al., 2013].

Despite the adopting current of educators around the world, “virtual only” simulators have an important impediment: they make a gap between the laboratory experiments while studying and the reality of working place after graduation. This is especially true to engineering graduates.

The present article introduces an intermediate method of teaching Electric Drive Systems and Control Systems Theory. In this article, is presented an electronic simulator for a dc electric motor. The same principle applied for the dc motor can be applied to any other physical system whose function can be expressed by linear time-invariant differential equations.

The article is structured in six chapters and covers the principle of the electronic simulator development starting with the mathematical equations and ending with the actual real implementation.

## 2 The transfer function and block schematic of electrical systems

In engineering applications, there are many situations in which the functions of certain systems are expressed by differential equations. Most of the times, in these applications, the numerical representation of the resulted function has to be analyzed and processed by other software or hardware systems.

In order to obtain the numerical solution of the response of a system to certain entrance signals, is a common practice to use graphic means of solving the equations. One practice applied both in the Control Systems as well as in Electrical Drive Systems is the use of Simulink/MATLAB or free equivalent software programs like Scilab.

The expression [1] illustrates a differential equation with null initial conditions. Most of the times in engineering differential equations are ‘time variable’ and describe the evolution of a certain system or installation in a period of time.

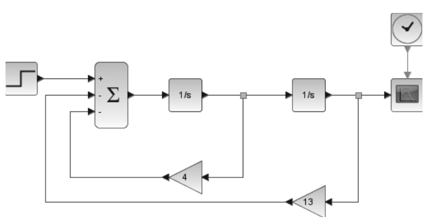
$$[1] \qquad \frac{d^2x(t)}{dx^2} + 4 \cdot \frac{dx(t)}{dx} + 13 \cdot x(t) = 65 \,,\, x(0) = 0 \,;\, \frac{dx(0)}{dx} = 0$$

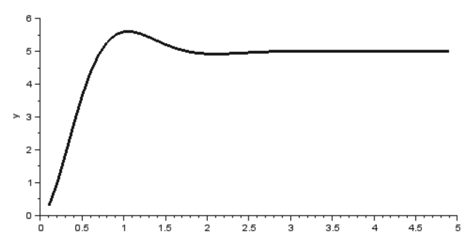
The equation [1] can be re-written in the format of expression [2].

$$[2] \qquad \ddot{x}(t) + 4 \cdot \dot{x}(t) + 13 \cdot x(t) = 65 \,,\; x(0) = 0 \,;\, \dot{x}(0) = 0$$

Solving the equation [1] by applying the analytical methods, results the mathematical expression of equation [3].

$$[3] \qquad x(t) = 5 - 5e^{-2t}\cos(3t) - \frac{10}{3}e^{-2t}\sin(3t),\; t \geq 0$$




a. Block representation
b. of equation [1]
c. Evolution in time of the solution of equation [1]

*Figure 2.* **Graphical representation of equation [1]**

In Electrical Engineering, there are situations in which the mathematical expression of the response signal does not present a high interest or is difficult to be obtained. In order to handle these situations was developed the Control System Theory. One of the most important aspects of this theory is to make a change from the real variable ‘t’ to a complex variable ‘s’ through the direct and inverse Laplace transform theory and algorithms.

The application of Control System procedures and algorithms to the equation [1] leads to the transfer function expressed by equation [4]. The solutions’ evolution in time of equation [4] can be obtained from the graphical representation displayed in Figure 2.a. Figure 2.b contains the evolution in time of the solution of equation [1].

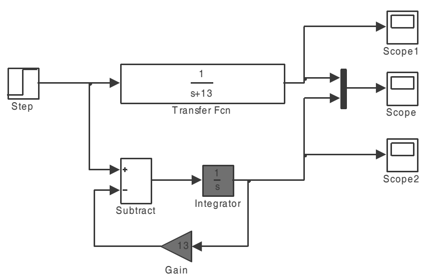
$$[4] \qquad X(s) = \frac{65}{s(s^2 + 4s + 13)}$$

The use of the concept of ‘transfer function’ makes it easier the analysis of complex technical systems.

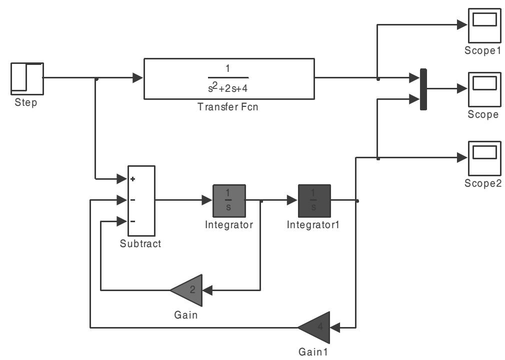
### 3 Electronic representation of transfer function and block schematic

A step further taken in the direction of electronic simulation is the implementation of bloc schematic such as displayed in Figure 2 using dedicated integrated circuits and networks of passive elements such as resistors and capacitors.

In the Control Theory, there are two types of standard systems that are studied and analyzed: first and second degree order systems. The degree order of such systems is according to the order of the numerator of the transfer function.




a. First degree order system




b. Second degree system

*Figure 3.* **Standard systems in the Control System Theory**

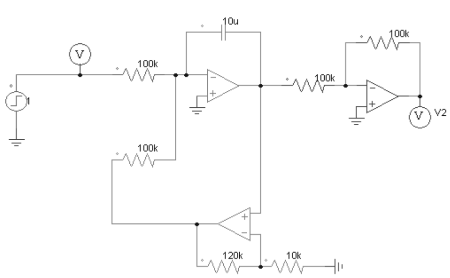
A first degree order systems' equation is indicated in equation [5] while a second degree order systems' equation is indicated in equation [6].

[5] $$G(s) = \frac{1}{s+13}$$

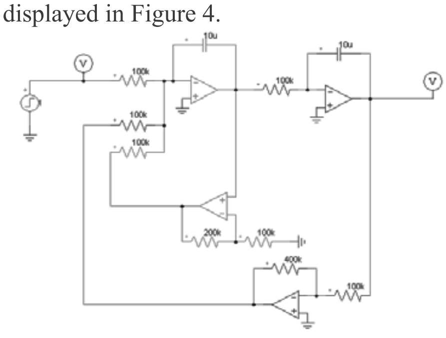
[6] $$G(s) = \frac{1}{s^2+2s+4}$$

Figure 3 displays the block diagrams of the 1st and 2nd degree order systems considered in equations [5]and [6]. The diagrams indicate the compact transfer function obtained from the equations and an expanded form of block implementation. Both representations have the same simulation results [Beloiu, 2015a].

By using OA and passive resistances and capacitors networks, the block schematics from Figure 3 can be implemented by electronic circuits displayed in Figure 4.




a. First degree order system




b. Second degree system

*Figure 4.* **Electronic implementation of block diagrams for 1st and 2nd degree systems displayed in Figure 3**

**4 Mathematical model of dc motor with field coil**

In Electrical Engineering, one of the basic systems that are studied is the direct current [dc] electric motor. This is due to its easy to understand equations and means to control. The essential electric structure of the motor consists in two coils installed on rotor and stator. The basic schematic of the dc motor is displayed in Figure 5.

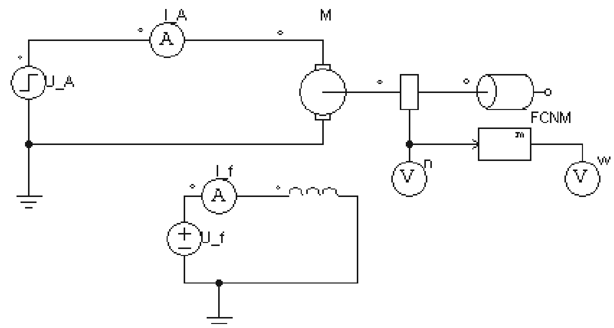



*Figure 5.* **DC motor schematic**

$$[7] \qquad \begin{aligned} U_A &= R_A i_A(t) + L_A \frac{di_A(t)}{dt} + K\Phi\Omega(t) \\ J\frac{d\Omega(t)}{dt} &= m - m_f - m_s \\ U_f &= R_f i_f(t) + L_f \frac{di_f(t)}{dt};\ \Phi = f(i_f) \end{aligned}$$

By applying the Kirchhoff theorems to the electrical circuits, results the equations' system that describes the dynamic behavior of the dc motor [Fransua et al., 1978] in equation [7].

Where:

- $U_A$ – voltage applied to motor's armature coil terminals; $U_f$ – voltage applied to motor's field coil terminals;
- $i_A$ – armature current; if – field current;
- $R_A$, $L_A$, $R_f$, $L_f$ – electric parameters of the motor armature and filed coils: resistance and inductance;
- $J$ – total inertial torque; $f$ – viscous friction coefficient;
- $m$ – electromagnetic torque; $m_f = f{\cdot}\Omega$ – viscous friction torque; $m_s$ – kinetic friction torque.

The Laplace transform applied to [7] under null initial conditions leads to the motors' transfer function expressed by equations [8]:

$$[8] \qquad \begin{aligned} U_A &= R_A I_A(s) + L_A s I_A(s) + K\Phi\Omega(s) \\ Js\Omega(s) &= K\Phi I_A(s) - f\Omega(s) - m_s \\ U_f &= R_f I_f(s) + L_f s I_f(s) \end{aligned}$$

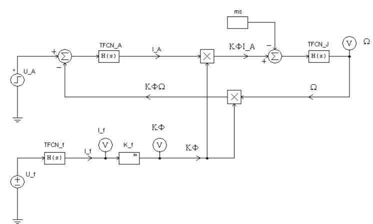



*Figure 6.* **Block diagram for a dc motor with separate excitation field**

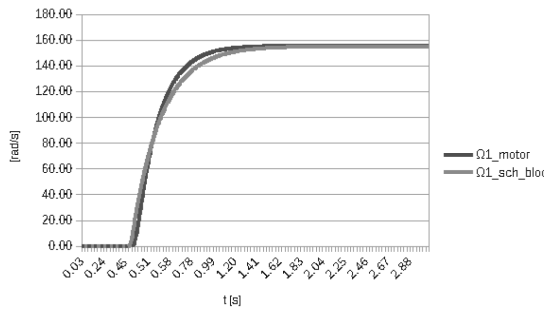



*Figure 7.* **Dynamic behavior of dc motor**

The dependency of the excitation flux and the field current $\Phi = f(i_f)$ can be determined through experimental measurements at nominal function conditions. This dependency is assumed to be constant regardless of the functional regime of the motor. The dynamic equation of the dc motor **Error! Reference source not found.** is converted into a block diagram displayed in Figure 6. The blocks TFCN_A/f are the implementation of the transfer function for armature and field electric circuits. The block TFCN_J implements the transfer function of the mechanical equation of the dc motor.

Figure 7 displays the dynamic behavior of the dc motor. **Ω**1 represents the speed for the motor acquired from the experimental data and software simulation [Figure 2], and **Ω**2 represents the output of the block diagram that simulates the dc motor [Figure 6]. Analyzing the two graphics it can be concluded that the block model of the motor is close approximation of the real motor tested in laboratory conditions.

### 5 Electronic simulator of the dc motor

The main theme of this article is the electronic implementation of the block schematic of a complex system, in particular, a dc motor displayed in Figure 6. The basic transfer functions used to model the dc motor, can be implemented by an OA combined with passive elements. The transfer function implemented by different electronic structures is indicated in Control Systems Theory manuals and books [Beloiu, 2015b][Ogata, 2010][Nise, 2011].

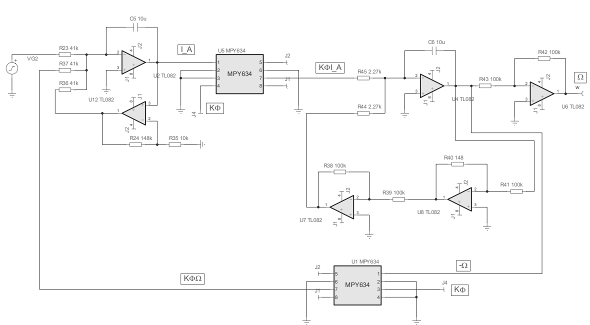



*Figure 8.* **Electronic implementation of the dc motor model**

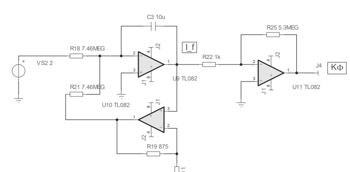



*Figure 9.* **Excitation field electronic circuit implementation**

In Figure 8, the circuits U2 and U12 implement the transfer function of the armature electric circuit $TFCN\_A = 1/\left(R_A + L_A s\right)$. The circuits U4, U8 and U7 implement the equivalent of the transfer function of the mechanical equations of the dc motor model $TFCN\_J = 1/(Js + f)$. Due to the change sign of the input signal of several OA structures, the output signal processed by the electronic simulator has to be multiplied by -1 so that it has the same sign as the input signal. This mathematical operation is implemented by U6 networked with R42 and R43.

The field circuit is simulated by the circuit displayed in Figure 9. The transfer function of the actual electric circuit $TFCN\_f = 1/(R_f + L_f s)$ is implemented by the circuits U9 and U10 and its' passive components networks. The output signal of this circuit represents the field excitation current I_e. In order to obtain the required parameter $K\Phi$, the I_e signal is multiplied by the K_f factor previously experimentally determined through direct measurements of the actual motor.

In Figure 6 appears two particular terms: $K\Phi I_A$ and $K\Phi\Omega$. These terms are obtained by multiplying the signals I_A/Ω with $K\Phi$. This operation of electronic multiplication of two signals is implemented in Figure 8 by the circuits U5 and U1. The transfer function of MPY634 circuit is indicated by its producer [TI, 2015].

The $K\Phi$ is applied by the jumper J4, which for U5 is connected to the $x_4$ input pin, while for U1 is connected to the $x_3$ input pin.

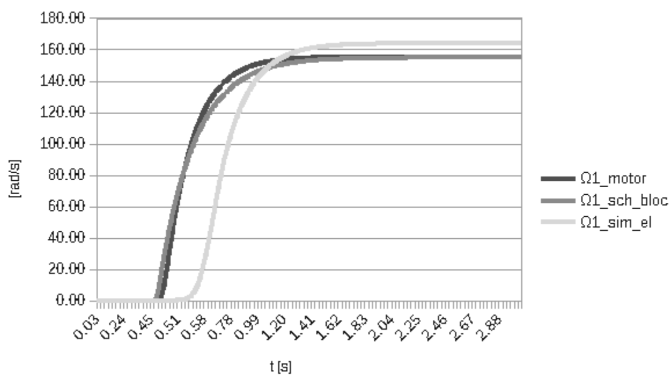



*Figure 10.* **Correlated output signals for: Ω1_motor –real motor output data; Ω1_sch_bloc – block schematic output data Ω1_sim_el – electronic simulator output data**

The mechanical parameters that are not indicated by the producer are determined experimentally in the laboratory, and its values are indicated in Table 2[Beloiu, 2014].

For the verification of the correct and accurate function of the presented electronic simulator, the output signal of the motor and the simulator have to be compared using the same unit scale. As they are totally different size and measurement systems, it has to be applied a correction scale indicator. The simulated output data with the electronic simulator has a minor delay in the rising domain and a slight difference in the steady domain of speed variation.

## 6 Conclusions

In this article was presented a solution for an electronic simulator for a dc electric motor. The presented method can be applied to any other physical system whose function can be described by linear and time-invariant differential equations.

The main advantage of this type of simulators over the "software only" simulator is that for a certain category of specialists is very important to be able to have access to "hands-on" laboratory experiments. By having access to electronic simulators, the students can still have the possibility of using measuring devices. Another important advantage is that complex systems can be simulated by electronic circuits. This method allows designers and engineers to have access to certain signals from the studied system for future processing.

The result presented in this article allows users, especially educators and students, to replace expensive stands for electric motors with more economically accessible electronic simulators without losing all the contact with the actual real systems. This method allows also the acquisition of different signals from the circuit. Thus it provides the users with the possibility of later processing.

**References**

Barrios, A., Panche, S., Duque, M., Grisales, V.H., Prieto, F., Villa, J.L., Chevrel, P., Canu, M., 2013. A multi-user remote academic laboratory system. Comput. Educ. 62, 111–122. doi: 10.1016/j. compedu.2012.10.011

Beloiu, R., 2015a. Hands-on solutions for teaching basic introductory control systems course. IEEE, pp. 89–93. doi:10.1109/ATEE.2015.7133751

Beloiu, R., 2015b. Teaching Control Systems in Electrical Engineering Education Programs, in: Progress in Education. Volume 37, Progress in Education. Nova Science Publishers, Inc., USA.

Beloiu, R., 2014. Dynamic determination of DC motor parameters - Simulation and testing. IEEE, pp. 13–18. doi:10.1109/ECAI.2014.7090191

Fransua, A., Magureanu, R., Cimpeanu, A., Condruc, M., Tocaci, M., 1978. Masini si Sisteme de Actionari Electrice. Probleme Fundamentale. Ed. Tehnica, Romania.

Kong, S.C., Yeung, Y.Y., Wu, X.Q., 2009. An experience of teaching for learning by observation: Remote-controlled experiments on electrical circuits. Comput. Educ. 52, 702–717. doi:10.1016/j.compedu.2008.11.011

Martin-Villalba, C., Urquia, A., Dormido, S., 2012. Development of virtual-labs for education in chemical process control using Modelica. Comput. Chem. Eng. 39, 170–178. doi:10.1016/ j.compchemeng.2011.10.010

Nise, N.S., 2011. Control Systems Engineering, 6th ed. JohnWiley & Sons, USA.

Ogata, K., 2010. Modern Control Engineering, 5th ed. Prentice Hall, USA.

Severino, S., Aiello, F., Cascio, M., Ficarra, L., Messina, R., 2011. Distance education: the role of self-efficacy and locus of control in lifelong learning. Procedia - Soc. Behav. Sci. 28, 705–717. doi:10.1016/j.sbspro.2011.11.132

Temiz, İ., Akuner, C., 2009. Comparison of traditional education to computer aided education: simulation of three-phase rotating area in an induction machine. Procedia - Soc. Behav. Sci. 1, 1825–1833. doi:10.1016/j.sbspro.2009.01.323

Texas Instruments, 2015. MPY634, http://www.ti.com/lit/ds/symlink/mpy634.pdf, Accessed September 2015.