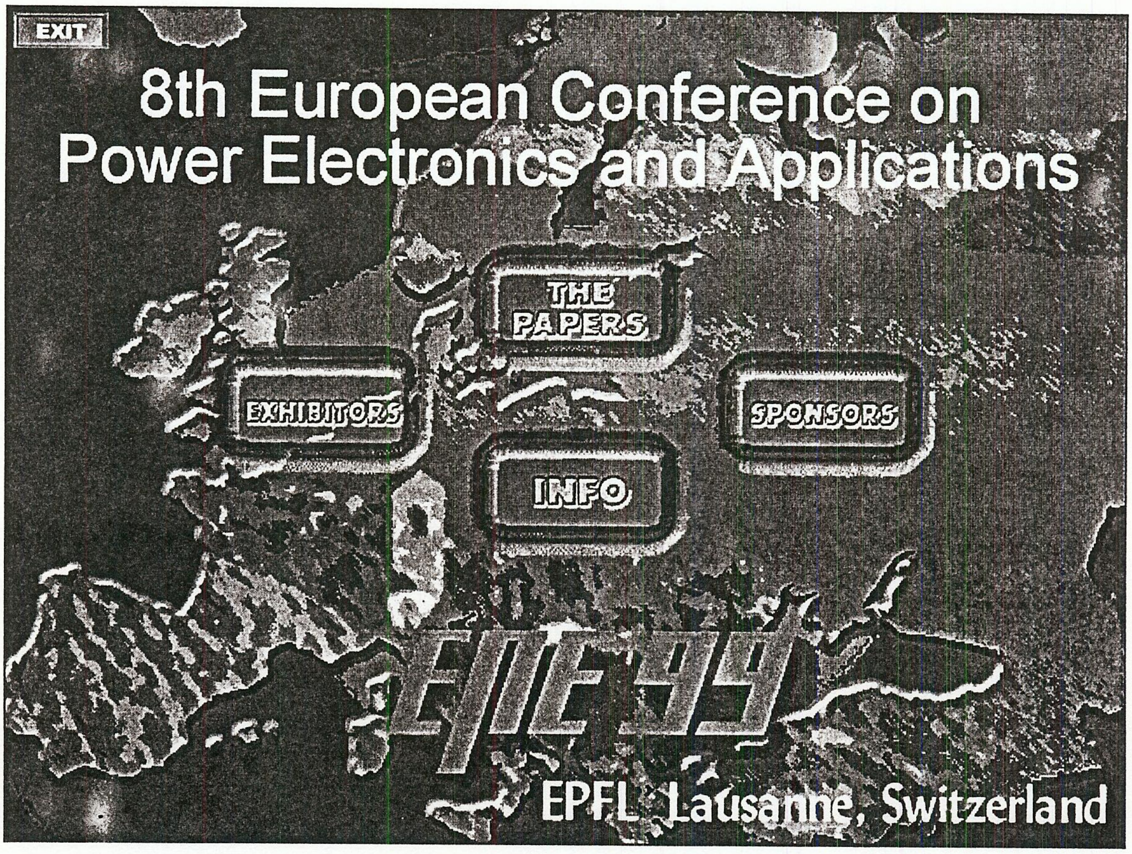
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XSIM: Software Package for Simulation of Induction Machines Suitable for Computed Assisted Education

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Keywords

AC machines, Education tools, Software

Abstract

This paper presents a software package for simulation of induction machines useful for training and computed aided education. The software collects the experiences of several years of study and research in the fields of control of induction machines, including vector control, space-vector and pulse width modulation techniques and fuzzy logic based control. The system has been designed in such a way that presents the machine as an induction motor with different loads (mechanical and electrical) or as an induction generator moved by a user definable torque. By incorporating the different procedures in a single package and by adding a user friendly interface and plot capabilities, a power tool has been obtained useful to introduce students to the most up-to-date solutions in the field of vector control of induction machines.

Introduction

The challenge of teaching modern electrical drives becomes more and more important in electrical engineering curricula since they belong to the class of multidiscipline systems which have to be discovered by the students, [5], [9]. With the technology evolution, it is more interesting to build systems with different components and to predict their behaviour in the large environment than in case of insulated subsystems. In this way, an electrical drive is the power system example in which mechanical, electrical machine, power electronics and control can be found. For the students, this fact is difficult to understand and analytical synthesis is not possible since most of the used models are non-linear. The only way to study the electrical drive performances is by digital simulation of the system. It is possible to illustrate directly on the screen the system performance (the effect of parameters changing and the behaviour of variables not easily available on actual drives) using a computer program that simulates the electrical drive. Also, students gain a deeper understanding of the system and its operation, learning to interact with it without danger.

In the past dc motors were used extensively in areas where variable speed operation was required since flux and torque could be easily controlled by the field and the armature current. In particular the separately excited dc motors have been used mainly for applications where there was a requirement of fast response and four-quadrant operation with high performance near zero speed. However, dc motors have certain disadvantages, which are due to the existence of the commutator and the brushes. They require a periodic maintenance and cannot be used in corrosive or explosive environments, and they have limited commutator capability under high-speed, high-voltage operational conditions. These problems can be overcome by the application of ac motors, which have a simple and rugged structure, high maintainability and economy, robust and immune to heavy overloading. Their small dimension, compared with dc motors, allow ac motors to be designed with substantially higher output ratings for low weight and low rotating mass.

The induction motor is a complex, non-linear system, with time-varying parameters. The dynamic performance of an ac machine is somewhat complex because of the coupling effect between the stator and the rotor phases, where the coupling coefficients vary with the rotor position. The machine model can be described by differential equations with time varying coefficients, [1], [2].

In this paper a software package for simulation of induction machines useful for training and computed assisted education is presented. The software collects the experiences of several years of study and research in the field of electrical machines and drives, [3], [4], [6], [7] and is a subsystem of an integrated environment for modelling, simulation and control of AC drives, [8]. The package is named XSIM (X-window Simulator of Induction Machines) and can be used not only to study the system behaviour, specially when parameters are not well estimated and adjusted or when strong load variations are applied, but also to obtain the initial controller of the real system.

Package Sub-systems

In order to analyse each part of XSIM package it is useful to divide it into different sub-systems:

Electrical Machines

The electrical drives are simulated by means of the analytical models described by a set of linear (in the continuous machine) and non-linear differential equations (in the induction machine) composed by the electrical and mechanical equations and the electromagnetic torque expression. In the following only the induction machine approach is referred to.

If the power supply is balanced three-phase, as is usually true when fed by a converter, the two-axis or d-q theory is normally used for dynamic modelling. In this theory, the time varying parameters are eliminated and the variables and parameters are expressed in orthogonal or mutually decoupled direct (d) and quadrature (q) axis. The d-q dynamic model of the machine can be expressed in either stationary or rotating (synchronously or rotor fixed) reference frame. The advantage in synchronously rotating frame model is that with sinusoidal supply, the variables appear as dc quantities in steady-state conditions. Expressions (1), (2) and (3) represent the electrical and mechanical behaviour of an induction machine, [1].

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{qr} \\ v_{dr} \end{bmatrix} = \begin{bmatrix} R_s + L_s \frac{d}{dt} & \omega_e L_s & L_m \frac{d}{dt} & \omega_e L_m \\ -\omega_e L_s & R_s + L_s \frac{d}{dt} & -\omega_e L_m & L_m \frac{d}{dt} \\ L_m \frac{d}{dt} & (\omega_e - \omega_r) L_m & R_r + L_r \frac{d}{dt} & (\omega_e - \omega_r) L_r \\ -(\omega_e - \omega_r) L_m & L_m \frac{d}{dt} & -(\omega_e - \omega_r) L_r & R_r + L_r \frac{d}{dt} \end{bmatrix} \cdot \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \tag{1}$$

$$T_e = \frac{3}{2} \cdot \frac{P}{2} \cdot \left(\vec{\phi}_s \otimes \vec{i}_s \right) = \frac{3}{2} \cdot \frac{P}{2} \cdot \left(\phi_{ds} i_{qs} - \phi_{qs} i_{ds} \right) \tag{2}$$

$$T_e - T_L = J \frac{d\omega_m}{dt} - B\omega_m \tag{3}$$

These differential equations are numerically integrated by means of the fixed or variable and first or fourth order Runge-Kutta algorithm.

Power Converters

The XSIM software includes the simulation of the following power converters components: uncontrolled single or three phase bridge rectifier, full-controlled three-phase bridge rectifier (voltage source inverter is simulated with a constant DC voltage as input) and three phase inverter. Power converters are simulated using ideal switches. This approach permits the description of the main system variables behaviour (including the currents flowing in each converter semiconductor) with a sufficient degree of accuracy without introduce further heavy calculations, as would be involved by the considerations of the internal semiconductor equations. Depending on the analysis demand, the supply stage is terminated by a LC filter on the DC line simulated by means of its differential equations.

In respect to the command strategies for the three-phase inverter, the classical bang-bang and PWM operations (sine-triangle as well as space vector modulation) are covered.

Controllers

In the XSIM program, the operator can define both, current and speed controller. The following types of controllers are available:

1. Standard PI and PID controllers.
2. PI and PID like fuzzy controllers.
3. Different kinds of current controllers: Bang-bang, PWM (sine-triangle and space vector modulation).
4. Implementation of field oriented techniques.

Analog or digital controllers can be defined and output limitation control actions are provided. Analog controllers are simulated using the same integration time of the controlled system (motor, load and power converters). In the case of digital controllers, the calculation step corresponds to a sampling step defined by the user (in this case each controller, current and speed controller, has a different sampling step).

Load torque

The program allows the operator to use the induction machine as a motor or as a generator, and supports different programmable loads (mechanical and electrical –by means of a coupled DC machine–). Load torque is easily configurable in a pop-up menu.

Package Structure

The XSIM package is based on a large collection of programs and routines written in the C language and developed under GNU C++ using Motif graphics libraries. It runs on UNIX workstations and a reduced version in simple personal computers under the MS-DOS operating system.

The program allows the user to choose one of the available configurations of the electrical drive and get theoretical information about it and the scheme. Figure 1 depicts available configurations of the electrical drive.

The induction machine can be:

- Configured to work as motor or generator.
- Without speed control. Electrical machine in open loop, fed by a six step (bang-bang, static PWM or space-vector PWM controlled) inverter.
- Speed scalar control by V/f characteristic.
- Speed direct/indirect vector (rotor flux oriented) control.

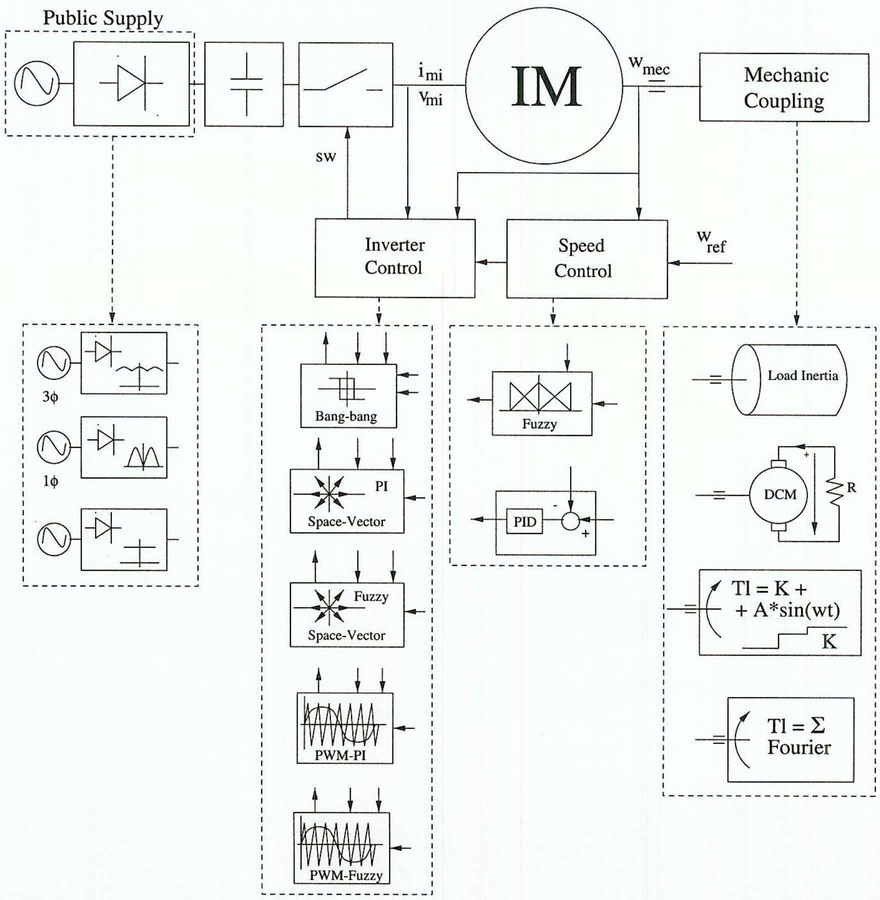

Fig. 1: Power system implemented by XSIM package.

Inside the application it is possible, depending on the system, to choose and compare different solutions ranging from controllers (classical PI or PID or fuzzy controllers) to current control techniques (bang-bang, static sine-triangle PWM techniques, dynamic and static space-vector PWM techniques) and load characteristics. Once the chosen application has been defined the user can start the simulation and follows on the screen the system evolution. At the end, the data can be stored in the hard disk in ASCII format for analysing or plotting. Different program screens are shown in figures 2, 3, 4, 5 and 6.

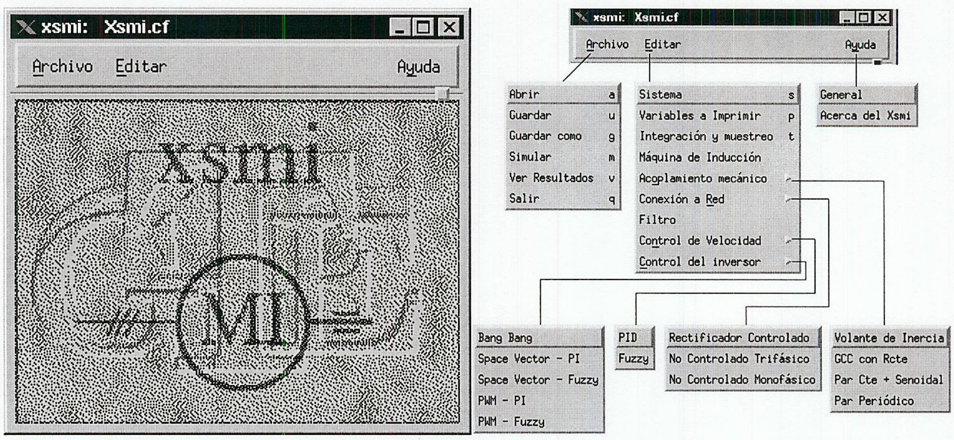

Fig. 2: XSIM: Input screen.

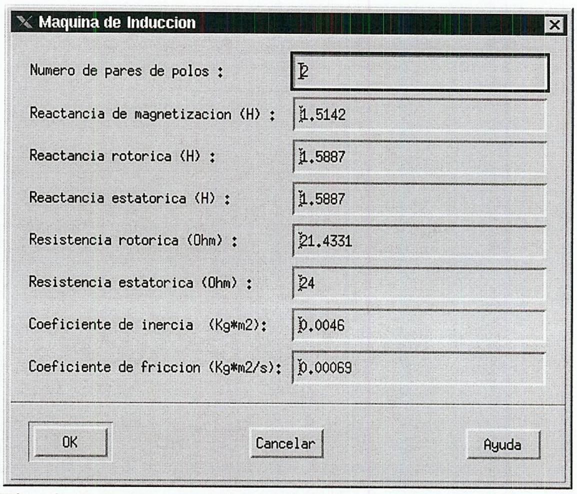

Fig. 3: Input screen for induction motor parameters.

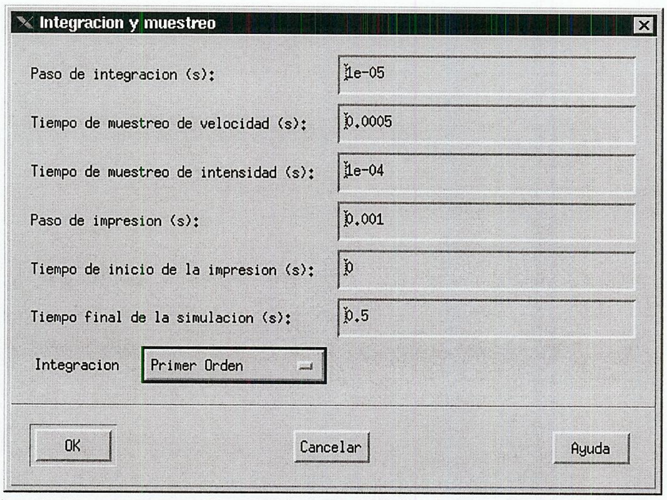

Fig. 4: Input screen for setting-up of the integration steps time.

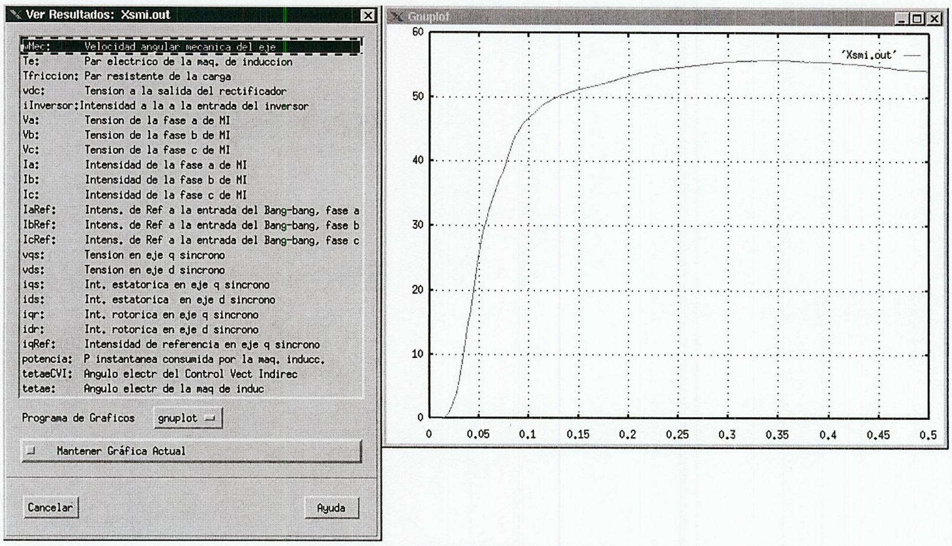

Fig. 5: Simulated results.

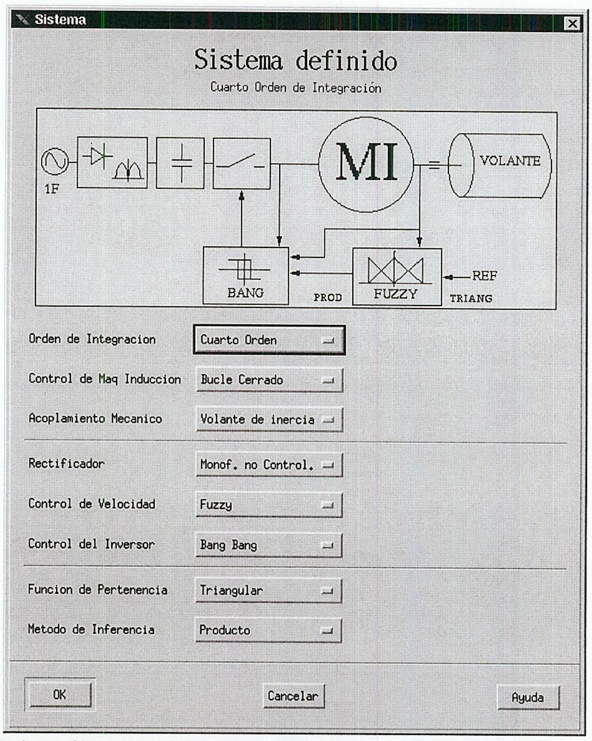

Fig. 6: Screen which describes the configuration made previous confirm a simulation process.

Conclusions

This paper presents XSIM, a software package for simulation of induction machines. By adding a user friendly interface, on-line help and plot capabilities, it represents a powerful tool suitable to introduce the end-course and post-graduate students in electrical engineering to the most advanced induction motor applications. The software has been integrated with a real IM test rig, [8], and has been shown to successfully predict system performance.

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