# USING VARIOUS COMPUTER TOOLS IN ELECTRICAL TRANSIENTS STUDIES

*Francisco Jurado[1], Natividad Acero[2], José Carpio[3] and Manuel Castro[4]*

***Abstract*** *¾ This paper discusses different computer tools used to help teach electrical transients studies in undergraduate courses in Electrical Engineering. The computer facilities and programs developed are discussed. The results of student surveys and the teaching staff's observations, are used to evaluate the usefulness of the different tools and determine their advantages and disadvantages.*

*Index Terms ¾ Induction motor, simulation.*

## INTRODUCTION

The number of tools suitable for transient analysis is increasing in the last few years. Besides the well-known EMTP and its variants ATP, PSCAD-EMTDC, etc, the general purpose mathematical program MATLAB is -with the introduction of the Power System Blockset- getting more and more powerful and can be used for electrical transient computations as well.

Computer tools to help professors and students alike in the teaching-learning process have become very popular [1,2]. The authors of the current paper set out to use several commercial packages, to study the possible advantages and disadvantages of using these tools in the electrical transient studies. To determine the effectiveness and shortcomings of the computer tools, all students were asked to fill several questionnaires. The tools for electrical transient computations are compared by their computational results and user-friendliness. This paper reports the results of this study, with the intention of giving other colleagues a more realistic view of the benefits and limitations of using computers in the classroom.

Using ATP, PSCAD-EMTDC and MATLAB-SIMULINK an induction machine is introduced, as a typical example of constant power load circuit. By lowering the voltage, also lowering the flux in the machine, then the current increase in order to keep the torque with a little increasing of the slip value.

## INDUCTION MOTOR LOAD

Induction motor load is an important component in power systems voltage stability assessment for the following reasons:

- It is a fast restoring load in the time frame of a second.
- It is a low power factor load with a high reactive power demand.
- It is prone to stalling, when voltage is low and/or the mechanical load is increased.

There are various types of inductor motors. In power system studies we usually assume aggregate motor models [3,4,5], i.e. one motor representing a large number of similar motors fed through distribution lines by the same substation. If the motors connected to the same bus are not similar, it may be necessary to use more than one aggregate motors to represent the load properly.

In terms of individual motor modeling, one has to distinguish between three-phase and single-phase motors, as well as motors having a constant rotor resistance and motors having double-cage, or deep bar rotor. Motor models with saturation, as well as with rotor resistance variable can be found in [6]. The effect of variable frequency is neglected for all load components.

The stator of a three-phase induction machine is similar to that of a synchronous machine. Using the Park transformation the three phase windings can be substituted by the two equivalent *d*- and *q*-axis windings. The rotor of an induction motor may have a short-circuited, three-phase winding, or a squirrel-cage construction. In either case, the rotor can be analyzed also with two equivalent, short-circuited, *d*- and *q*-axis windings. The following types of transients are present in an induction machine:

- Stator transients similar to those of synchronous machines.
- Rotor electric transients involving the *d*- and *q*-axis equivalent rotor circuits. These are in the time frame of subtransient generator time constant (damper windings).
- Rotor mechanical motion characterized by the corresponding acceleration equation.

Usually it is assumed that the rotor electric transients are faster than the mechanical transients, so that the motor can be represented with only acceleration dynamics. In [7] it is shown that this assumption is valid for small motors, whereas an alternative reduced order model can be used for large motors. Typical equivalent circuit parameters for small industrial motors are in [6,8], large industrial motor in [8],

---

[1] Francisco Jurado, University of Jaén, Department of Electrical Engineering, 23700 EUP Linares (Jaén), Spain, fjurado@ujaen.es
[2] Natividad Acero, University of Jaén, Department of Electrical Engineering, 23700 EUP Linares (Jaén), Spain, nacero@ujaen.es
[3] José Carpio, UNED, Dept. of Electrical and Computer Engineering, 28040 Madrid, Spain, jose.carpio@ieec.uned.es
[4] Manuel Castro, UNED, Dept. of Electrical and Computer Engineering, 28040 Madrid, Spain, Manuel.Castro@ieec.uned.es

mean values for 11 kVA motors in [9], aggregate residential motors in [8] and single phase motors in [10]. The program *Induction motor parameters* generates the equivalent circuit of a wound rotor, single cage, double cage or deep bar induction motor, based on performance data entered by the user [11].

When the voltage on an induction motor undergoes a step decrease, the induction motor load will immediately drop. This occurs because the machine slip cannot change instantaneously. However this creates a mismatch between electrical and mechanical power which forces a restoring change in the slip. The load therefore quickly recovers.

## DESCRIPTION OF THE COMPUTER TOOLS

### Alternative Transient Program (ATP)

ATP is a universal program system for digital simulation of transient phenomena of electromagnetic as well as electromechanical nature. With this digital program, complex networks and control systems of arbitrary structure can be simulated.

ATP has extensive modeling capabilities and additional important features besides the computation of transients. It has been continuously developed through international contributions over the past 20 years [12].

Operating Principles:

- Basically, trapezoidal rule of integration is used to solve the differential equations of system components in the time domain.
- Non-zero initial conditions can be determined either automatically by a steady-state, phasor solution or they can be entered by the user for simpler components.
- Interfacing capability to the program modules TACS (Transient Analysis of Control Systems) and MODELS (a simulation language) enables modeling of control systems and components with nonlinear characteristics such as arcs and corona.
- Symmetric or unsymmetric disturbances are allowed, such as faults, lightning surges, any kind of switching operations including commutation of valves.
- Calculation of frequency response of phasor networks using FREQUENCY SCAN feature.
- Dynamic systems also can be simulated using TACS and MODELS control system modeling by itself.

Components:

- Uncoupled and coupled linear, lumped elements.
- Transmission lines and cables with distributed and frequency-dependent parameters.
- Elements with nonlinearities: transformers including saturation and hysteresis, surge arresters, arcs, corona.
- Ordinary switches, time-dependent and voltage-dependent switches, statistical switching (Monte-Carlo studies).
- Valves (diodes and thyristors).
- 3-phase synchronous machine, universal machine.

MODELS in ATP is a general-purpose description language supported by an extensive set of simulation tools for the representation and study of time-variant systems,

- The description of each model is enabled using free-format, keyword-driven syntax of local context and that is largely self-documenting.
- MODELS in ATP allows the description of arbitrary user-defined control and circuit components, providing a simple interface for connecting other programs/models to ATP.
- As a general-purpose programmable tool, MODELS can be used for processing simulation results either in the frequency domain or in the time domain.

Supporting Routines:

- Calculation of electrical parameters of overhead lines and cables using program modules LINE CONSTANTS, CABLE CONSTANTS and CABLE PARAMETERS.
- Generation of frequency-dependent line model input data.
- Calculation of model data for transformers.
- Saturation and hysteresis curve conversion.
- Data modularization (for $INCLUDE).

Output:

- Time-varying output in printed lists, character plots, or vector plots using separate interactive graphic programs TPPLOT, PCPLOT, PlotXY. HP-GL and PostScript also can be produced.
- Postprocessing of monitored variables using MODELS and/or TACS, Fourier analysis.

Most users, including program developers, use Intel 486/Pentium based PC's with Ms-Windows 3.x/95/NT. A standard PC configuration with 8-MB RAM, hard disk (10 MB free space) and VGA graphics is sufficient to execute ATP under MS-DOS/MS-Windows. ATP is available for other computers, too.

ATP-EMTP tables are dimensioned dynamically at the start of execution to satisfy the needs of users and their hardware (e.g., RAM). No absolute limits have ever been observed, and the standard version has limits that average more than 20 times default table sizes. Today, the largest simulations are being performed using MS-DOS computers. Default table sizes: buses 3000, branches 3000, switches 1200, sources 340, nonlinear elements 460, synchronous machines 45.

Additional tool is PCPLOT, a simpler interactive graphical output tool available separately as DOS program and 32-bit program PCPlot for Windows 95/NT with features such as HPGL output, screen copy, zoom function, etc.

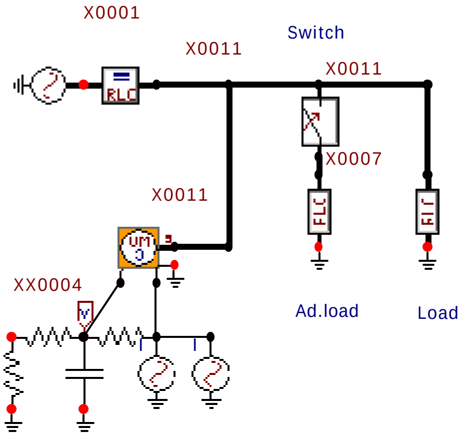

FIGURE 1.
INDUCTION MOTOR LOAD USING ATP.

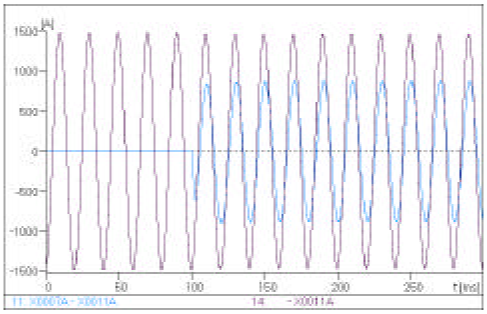

FIGURE 2.
VARIATION OF THE VOLTAGE OF INDUCTION MOTOR USING ATP.

## PSCAD/EMTDC

EMTDC is a transients simulator which has been evolving since the mid-1970's. Originally inspired by Dr. Hermann Dommel from his classic April 1969 IEEE paper published in the Transactions on Power Apparatus and Systems, its development has always been completely independent of EMTP and its many derivatives [13].

PSCAD is a powerful graphical user interface that integrates seamlessly with EMTDC, a general purpose time domain program for simulating power system transients and controls. Together they provide a fast, flexible and accurate solution for the simulation of virtually any electrical equipment or system.

PSCAD/EMTDC represents and solves the differential equations of the entire power system and its controls in the time domain (both electro-magnetic and electro-mechanical systems). This class of simulation tool differs from load flow and transient stability tools, which use steady state equations to represent electrical circuits (i.e. electro-magnetics), but solve the differential equations of machine mechanical dynamics (i.e. rotational inertia).

PSCAD/EMTDC results are solved as instantaneous values in time, but can be converted to phasor magnitudes and angles via built-in transducer and measurement functions (like true-rms meters or FFT spectrum analyzers...), much the way real system measurements are performed. Since load-flow and stability programs work with steady state equations to represent the power system, they output fundamental frequency magnitude and phase information only.

The PSCAD simulation tool can therefore duplicate the response of the power system at all frequencies, bounded only by the user-selected time step which can be varied from nano-seconds to seconds. Typical studies which can be performed are:

- Find overvoltages in a power system due to a fault or breaker operation. Transformer non-linearities (i.e. saturation) are a critical factor and are represented. Multiple run facilities are often used to run hundreds of simulations to find the worst case when varying the point on wave of the fault, type of fault, or location of the fault.
- Find overvoltages in a power system due to a lightning strike. This simulation would be performed with a very small time step (nano-seconds).
- Find the harmonics generated by a SVC, HVDC link, STATCOM, machine drive (virtually any power electronic device). Detailed models for thyristors, GTO, IGBT, diodes.. are required, as are detailed models of the associated control systems (both analogue and digital).
- Find maximum energy in a surge arrester for a given disturbance.
- Tune and design control systems for maximum performance. Multiple run facilities are often used here as well to automatically adjust gains and time constants.
- Investigate the Sub-Synchronous Resonance (SSR) effect when a machine and multi-mass turbine system interacts with series compensated lines or power electronic equipment. Controls systems can also be modified to investigate possible SSR mitigating methods.
- Modeling of STATCOM or Voltage Source Converters (and detailed models of their associated controls)
- Study interactions between SVC, HVDC and other non-linear devices.
- Investigate instabilities due to harmonic resonances, controls, interactions...
- Investigate the pulsing effects of diesel engines and wind turbines on the electric network.
- Insulation coordination.
- Variable speed drives of various types including cycloconverters and transportation and ship drives.

- Industrial systems including compensation controllers, drives, electric furnaces, filters, etc.
- Feeds to isolated loads.

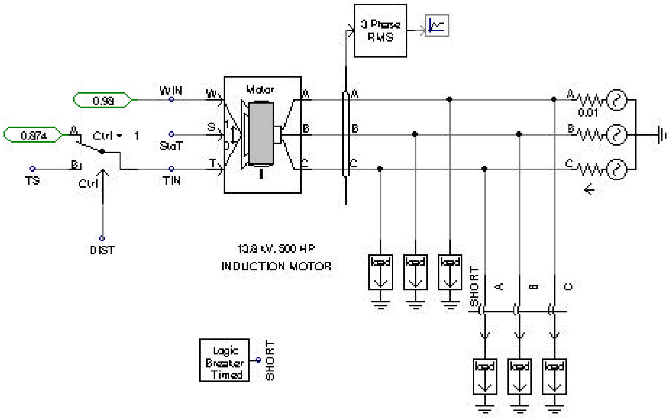

FIGURE 3.
INDUCTION MOTOR LOAD USING PSCAD/EMTDC.

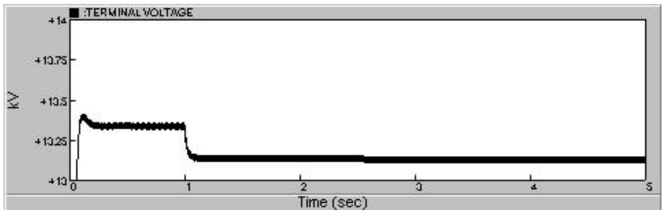

FIGURE 4.
VARIATION OF THE VOLTAGE OF INDUCTION MOTOR USING ATP.

## MATLAB

MATLAB® is a high-performance language for technical computing that includes functions for numeric computation, data analysis, algorithm prototyping, system simulation, and application development [14].

Graphical user interfaces supported: X Windows/Motif, Microsoft Windows, and Macintosh (MATLAB 5.2) environments.

Operating systems supported: Windows 95/98/NT, Macintosh OS (MATLAB 5.2), UNIX, Linux, OpenVMS (MATLAB 5.0); Multibyte character support.

Computer platforms supported: Intel 486 or Pentium PCs, Macintosh (MATLAB 5.2), SunSPARC, DEC Alpha, SGI, SGI64, HP 9000/700 and 800, IBM RS/6000.

Multiplatform interoperability: MATLAB applications are fully transportable without modification across platforms. MATLAB data files (MAT-files) from different environments are converted automatically.

MATLAB offers a unique simulation and prototyping environment. The powerful technical language is both concise and descriptive, allowing you to model complex systems with small sections of easy-to-follow code.

MATLAB and companion products offer an array of tools for simulation and modeling, including:

- A large collection of high-performance functions for mathematical computation, data analysis, equation solving, and visualization, all available as part of core MATLAB.
- Additional state-of-the-art algorithms in MATLAB add-on Toolboxes.
- Simulink and Stateflow block-diagram graphical design environments.

Power System Blockset is a state-of-the-art design tool, developed by scientists and researchers at TEQSIM, Inc., and Hydro-Québec, for modeling and simulating electric power systems within the Simulink environment.

Power System Blockset block library contains Simulink® blocks that represent common components and devices found in electrical power networks. Most of the blocks are based on well-known electro-magnetic and electro-mechanical equations. These blocks use standard electrical symbols, making it easy to create intuitive graphical models of electrical power systems.

Power System Blockset extends Simulink to provide a unique environment for multidomain modeling and controller design. By connecting the electrical parts of the simulation to blocks from Simulink's extensive modeling library, you can rapidly draw the circuit topology and simultaneously analyze the circuit's interactions with mechanical, thermal, and control systems.

Key features:

- Provides topological modeling and simulation of electrical power systems within Simulink.
- Uses standard electrical symbols for intuitive modeling of power systems.
- Includes standard blocks for AC motors; transformers; transmission lines; generators; and a wide variety of devices, including circuit breakers, diodes, GTOs, MOSFETs, and thyristors.
- Delivers highly accurate simulations of power system models using the powerful variable-step integrators and zero-crossing detection capabilities in Simulink.
- Compute state-space representations of your circuit, steady-state currents and voltages, set or reset initial currents and voltages and compute load flow for machines
- Includes a library of pre-assembled block models for power system networks, electric machinery, power electronics, control and measurement blocks, and triphase components.

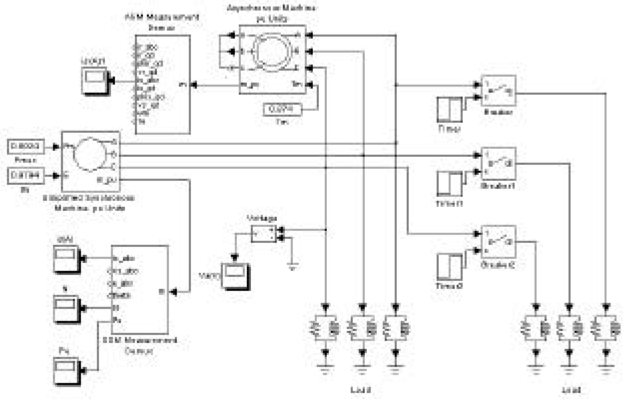

FIGURE 5.
INDUCTION MOTOR LOAD USING MATLAB.

## TUTORIALS

Based on the simulation packages described above, an induction machine is introduced, as a typical example of constant power load circuit. By lowering the voltage, also lowering the flux in the machine, then the current increase in order to keep the torque with a little increasing of the slip value. The main goal was to allow the student to review important equations and concepts discussed in lectures, through personal unsupervised use. The tutorials were developed to give students a choice of simulation package and to allow the teaching staff to determine the advantages and disadvantages of the different programs.

## RESULTS

To determine how the computer tools were being used, students were asked to answer several questionnaires throughout the term. The surveys concentrated on determining the students previous knowledge of software and computers, with particular interest in their familiarity with and use of simulation packages. The questionnaire included a question on the students expectations of the use of these packages. Table I shows the students' answers to the Main questions in the survey.

TABLE I
RESULTS OF SURVEY. STUDENTS

| Item | # |
|---|---|
| Participation | 95 |
| Familiar with PC | 94 |
| Familiar with Internet | 89 |
| Familiar with ATP-EMTP | 1 |
| Familiar with PSCAD-EMTDC | 1 |
| Familiar with MATLAB | 10 |
| Simulation packages were helpful | 81 |
| Computer used for word processing | 62 |
| Computer used for programming | 14 |
| Computer used for data analysis | 20 |
| Computer tools would be helpful | 93 |

TABLE II
RESULTS OF SURVEY. COMPUTER TOOLS

| Item | Helpful | Some | Little |
|---|---|---|---|
| ATP-EMTP | | | |
| Number of circuit element models | 65 | 25 | 5 |
| Programming freedom and flexibility | 59 | 31 | 5 |
| PSCAD-EMTDC | | | |
| Number of circuit element models | 58 | 33 | 4 |
| Programming freedom and flexibility | 53 | 38 | 4 |
| MATLAB | | | |
| Number of circuit element models | 45 | 44 | 6 |
| Programming freedom and flexibility | 70 | 21 | 4 |

## CONCLUSIONS

Laboratory exercises are an important part of an electrical engineer's education. This view is constantly reinforced by feedback from members of our departments that includes representatives from industry. One of the main difficulties with laboratory exercises is that they require resources that may be beyond reach for most electrical engineering departments [15]. For a more complete discussion of the advantages and disadvantages of laboratory exercises, the reader is referred to [16]. Our experience at the Universities of Jaen and UNED, shows that an effective laboratory exercise can be designed as part of senior elective classes with limited resources.

Computer simulations allow the student to experiment with mathematical models and develop a feel for their limitations. However, the authors believe that simulations can never take the place of hands-on experiments. We can argue, although there are problems simulating, we do not realize how enormously different the simulations will be from our implementation problems.

Several important conclusions can be drawn from the survey. First, the majority of the students were familiar with the hardware, and a relative large number of them were used to computer communications. Few students had used simulation packages before, and these considered this type of software useful. Computers were mostly used for word processing, as indicated before. Finally, the great majority of the students felt that using the simulations packages in the course would be helpful.

With regard to the computer tools:

- ATP and PSCAD scores best where the number of circuit element models is concerned.
- MATLAB is unbeatable where programming freedom and flexibility are concerned.

## REFERENCES

[1] "Special issue on computation and computers in electrical engineering education," *IEEE Trans. Education*, Vol. 36, No. 1, February 1993.

[2] Huelsman L. P., "Personal computers in electrical and computer engineering: Education survey," *IEEE Trans. Education*, Vol. 34, No. 2, May 1991, pp. 175-178.

[3] Rogers G., Di Mano J., and Alden R.T.H., "An aggregate induction motor model for industrial plants," *IEEE Trans. on Power Apparatus and Systems*, 103, pp 683-690, 1984.

[4] Nozari F., Kankam M.D., and Price W.W., "Aggregation of induction motors for transient stability load modelling," *IEEE Trans. Power Systems*, Vol. 2, pp. 1096-1102, 1987.

[5] Stankovic A.M., and Lesieutre B.C., "Probabilistic approach to aggregate induction machine modeling," *IEEE Trans. on Power Systems*, Vol. 11, pp. 1983-1989, 1996.

[6] Kundur P., *Power System Voltage Stability*, New York, McGraw-Hill, Inc, 1994.

[7] Ahmed-Zaid S., and Taleb M., "Structural modeling of small and large induction machines using integral manifolds," *IEEE Trans. on Energy Conversion*, Vol. 6, pp. 529-535, 1991.

[8] IEEE Task Force, "Standard load models for power flow and dynamic performance simulation," *IEEE Trans. Power Systems*, Vol. 10, pp. 1302-1313, 1995.

[9] Franklin D.C., and Morelato A.,"Improving dynamic aggregation of induction motor models," IEEE Trans. Power Systems, Vol. 9, pp. 1934-1941, 1994.

[10] Taylor C.W. Power System Voltage Stability, New York, McGraw-Hill, Inc, 1994.

[11] Furst G.B. Induction Motor Parameters. Generation of Coil Resistances and Inductances from Motor Performance Data for the use in U.M. Version 1. 0 C, EMTP-ATP Users Group.

[12] ATP, EMTP-ATP Users Group.

[13] PSCAD/EMTDC, Manitoba HVDC Research Centre, Winnipeg, Manitoba, Canada.

[14] MATLAB, Math Works, Inc., Natick, MA, USA.

[15] Orr J. A., and Eisenstein B.A., "Summary of Innovations in Electrical Engineering Curricula," IEEE Trans. Education, Vol. 37, No. 2, May 1994, pp. 131-135.

[16] Wankat P.C., and Oreovicz F.C., Teaching Engineering, McGraw Hill, NY, 1993.