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On the return to Geometry in lecturing Technology

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1. Introduction

The traditional way of teaching mainly spreads the information out of the textbook and poses the solution of problems through memorization of formulas and facts. A change to more dynamic and hands-on methods has been adopted by many teachers and new innovative techniques are being applied in education. Technology can be a powerful strategy for change in education. The use of technology in the classroom can give all students a learning environment that allows and enhances discovery and creativity through the use of computer and educational software. The technological impulse in education is especially useful for the improvement of the teaching and learning process in Science and Technology.

In recent years, it is observed a generalized trend to create continuously even more sophisticated educational software. The approach for this is to design virtual environments plenty of details and options, in order to emulate real world, as close as posible. All the members of university community appreciate much these type of programs, because it allows students the acquisition of skills that will be probably required in their professional career. Nowadays, simulation programs are often used as a supplementary mean for the teaching of science and technology, especially when learning of a particular subject can not be accomplish through experiments and practice due to practical difficulties, and/or dangerous or expensive testing.

This can lead to a methodological dichotomy related to educational technology. On one hand, it can be found a huge development of computing resources, an increase on application issues for practice and experimentation. In contrast, there are few tools and limited perfomance of software applications for the understanding and reinforcement of theoretical concepts. In addition, there exists more active participation of students in practical applications, designed with a much more attractive and interesting presentation for students, increasing their motivation. On the contrary, passivity and lack of student motivation are usually proportional to the amplitude and complexity of the theory.

Consequently, the higher education may tend to enhance practical and rewarding usefulness and relegate the theoretical background to a lower level of enphasis. Hence, students may become professionals with excelent skills in the practical aspects of work, though with less solid understanding and knowledge of theory.

2. Geometry for lecturing Science and Technology

Fortunately, it is now a commonplace to remark the benefits of the ICT for education. In practice, all the members of teaching staff use, to a greater or lesser extent, some sort of technological resources to improve features of their teaching. The present educative reforms in some countries promote the use of the technologies as a support of the learning and teaching process and students are demanded to acquire skills related to personal computer and significant ICT tools.

There are several tendencies in the usage of technology for education. These trends are related to the hardware and software technologies. The first one is about the design of hardware devices. They are increasingly sophisticated and tend to integrate all types of multimedia resources. An example of this trend is the creation of the digital or electronic blackboard as a tool for teaching.

The second trend is the use of communication in support of teaching and learning, primarily using the online campus. It is used even if teaching and learning of subject matters is performed in a classroom. This trend enables the introduction of various materials, such as text, video, audio and others, with many formats and applications to widen the class issues.

Finally, there is a trend towards the creation of educational software. In the courses, computers support practical experimentation with computer simulations and other multimedia components, such as animations, video and audio clips, graphics and so on.

The main objective of an educational software project in science and technology is to integrate different ICT tools in teaching and learning. Most software programs claim to be very efficient for the teaching of knowledge in the theme and practical application of specific techniques.

There is a great number of applications of educational software and scholars have published a huge amount of didactic experiences. Despite the diversity in computer based learning environments, the software programs can be classified into three main categories based on their pedagogical approaches: Dynamic Learning Systems, Computer Systems, and Intelligent Tutoring Systems. Dynamic Learning Systems promote learning by discovery. Computer Systems aim improving the cognitive abilities of learners through the shift of focus from procedure to thinking. Intelligent Tutoring Systems try to integrate artificial intelligence principles into education.

Two features of education in science and technology have been emphasised by software programs: a) Calculus and mathematical operations, for instance, the Excel spreadsheet that embeds mathematical functions and diagrams. b) Simulation of laws, machines, systems, processes, structures, and so on. The most relevant applications of simulation in education are the remote laboratory and virtual laboratory. The remote laboratory exercises in real laboratory with the aid of hardware devices and appropriate software computer, data acquisition, control system and ICT tools. Virtual laboratory activities, based on computer simulations, artificially reproduce various science phenomena and complicated, expensive or inaccessible devices. They are the most promising though time consuming tecniques in educational software.

Much attention has been paid to computer environment in order to help students to understand the practical features and the enhancement of practical skills, However, few of software programs are dedicated to harness the theoretical knowledge of the subject matter.

Therefore, it can be advisable to use computer programsm to help students in working Geometry and handling the geometric transformations implicitly found out through

mathematical formulas in textbooks. With this modus operandi, it is reinforced the knowledge of theory, which is more difficult to understand and retain.

2.1 Advantages of Geometry-based software

In general, the teaching of the theory of subject matter is based on the oral explanation in class, with the aid of textbooks. Animated graphics, simulations and multimedia resources prepared to this effect can help for explanations, and there are many software tools in the market to help the teacher or educational support services in preparing such tools.

Depending on the level of the technological evolution of the institution and teachers, a student may face to an heightened number of different programs, each one with their own objectives, operational procedures and distinguished features. The benefits of these programs do not always overpass their disadvantages. The cost of the acquisition and maintenance of software can be substantiated by the use made of such programs. Changes in licensing policy of the owner firms may generate uncertainty in the acquisition of such programs, and technological changes also encourage the development of new educational software, so that the previously acquired software becomes rapidly obsolete. Many prefer the free software as a means to overcome these disadvantages, though it does not usually reach the performance of commercial programs.

In the teaching of technological matters, much of the theoretical explanations use concepts and formulas with evident geometric meanings. The full list of examples would be uncountable. A quick glance at a textbook in technology and engineering would probably find many hints of support for the theory based on geometric concepts, such as the sum of vectors, second-order equations, equilibrium points, linear equations, and similar.

It is not intended to state that the mathematical foundations of textbooks in science and technology are simple. The university must provide a substantial mathematical preparation during the undergraduate courses to successfully cope with especialized subjects in the field. Here, it is intended to stress that formulas, which are normally used in both the simplified theoretical model and practical applications, are not of special difficulty, unlike the problem under consideration, which may be of great complexity. The development of high-tech silicon industries and powerful algorithms empower the solution using computers of intractable problems to human capacity. In recent times, there are even competitions among supercomputers for solving problems of more than 100 million variables. Also, the aim is to remark that little attention is devoted to improve the teaching of theory through educational software. It is noted that many of the theoretical concepts are expressed with geometric formulas (Cederberg, 2004). Hence, the knowledge of the theoretical basis is deepened with simulations based on the geometry. A return to Geometry and the use of geometry-based programs are proposed. One of the advantages of working with Geometry is the student's familiarity with the concepts discussed in their pre-university period. In addition, it can be used the same computer programs at the secondary school, without the need to adapt them to the university environment, only the specific examples that are need to be designed. The adoption of simple software in Geometry also allows teachers to explore the creativity of students as they can design their own examples, which allows the design of teaching the course with a collaborative approach.

There are different strategies to incorporate Geometry in teaching technology:

a) The simpler strategy is to depict the geometrical concepts and formulas in textbooks, which is the most frequent one in secondary school.

b) Other strategy is to find out the geometrical representation of formulas. In this work, the analysis of symmetrical component in electrical power system is presented as an example of teaching theory using this strategy.
c) A refined strategy is to transform the mathematical formulas to achieve the analoguous geometric formulation. The analysis of the response of an automatic control system is focused on this strategy in this work and provides a fine example of helping research using Geometry.
d) A complementary strategy may be the preparation of animated textbooks. A brief discussion is made to present some packages that may perform this strategy and produce stand-alone textbooks.

2.2 CABRI description

As a result of Dynamic Learning approach, Interactive Geometry Software are computer programs which allow the creation and manipulation of geometric constructions, primarily in plane geometry. Cabri, GeoGebra and similar IGS programs try to work with simple concepts, without operational difficulty (Dreyfus et al., 1998). The quality of simulations one can build with these software programs in physics, engineering, astronomy, technical drawing or art, widens its use far beyond mathematics and helping much the student to reinforce and to deepen in the theoretical knowledge of the technological matters. In this work, Cabri examples have been chosen to illustrate the exposition.
Cabri Geometry is a commercial IGS produced by Cabrilog for teaching and learning geometry and trigonometry. Cabri handles all the constructions students have traditionally done with personal instruments. Lines, circles, points, triangles, vectors, conics, etc are easily created, manipulated and measured with toolbars and drop-down menus. Using powerful functions Cabri empowers geometrical exploration from simple figures to the most complicated for use and research in university. Students can see patterns, make conjectures, draw their own conclusions, and create alternative examples of the construction. Characteristics of figures are retained throughout transformation. An additional and interesting feature of Cabri is that plots curves of similar functions dependent on one or more parameters, which are modifiable by varying or animating the parameters.
It is preferred Cabri to others because it is easy to use and there are numerous Cabri examples that have been created during last years. In addition, applets for publishing the examples in internet can be prepared using CabriWeb. These applets may be available to anyone who has a computer connected to the Internet that can run Java.
There is, also, the benefit of having the students an easy-to-use and familiar tool at the start of activity in undergraduate studies. The focus and content of those activities can be on the behavior or properties of the phenomena being modeled by this tool, rather than on the mathematics of the modeling execution. Students can work at a higher level of mathematical sophistication without requiring analogously higher level of technical or conceptual sophistication with the software, since Cabri encapsulates both basic and sophisticated mathematical construction.

3. Geometry in Power Systems. The case of symmetrical components.

Although there are some industrial applications of electric power systems in direct current DC, the textbooks usually deal only with those based on the alternating current AC. The mathematical analysis of AC systems operates with complex numbers and variables, which have a geometric representation as vectors in a plane.
An extended version of vectors including changes in module and/or direction over time are phasors. The main electric magnitudes, such as currents and voltages, are presented as functions of time t and angular velocity ω. The phasors in a given electrical system are vectors that change their direction and amplitude depending on the factor ωt, though they have constant relative positions between them. Normally they are studied in a rotating reference frame, which makes them stationary.
Performance of an electrical device or system may be fully described by its phasorial diagram. This is important to establish the functional relations and mutual influences among the different components of an electrical system. The elements of a power system are the machines, transformers, transmission lines and loads connected to the system. In a 3-phase power system, phasors of current and voltages are balanced in normal operation. The 3-phase electric magnitudes, current or voltage, are formed by three phasors with the same amplitude and a phase lag of 120º between two of them. In Figure 1, on the left, it is drawn the sinusoidal ωt-dependent function of a generic balanced 3-phase system M, defined by:

$$M_R = 5\sin\omega t\,;\; M_S = 5\sin(\omega t - 2\pi/3)\,;\; M_T = 5\sin(\omega t - 4\pi/3)$$

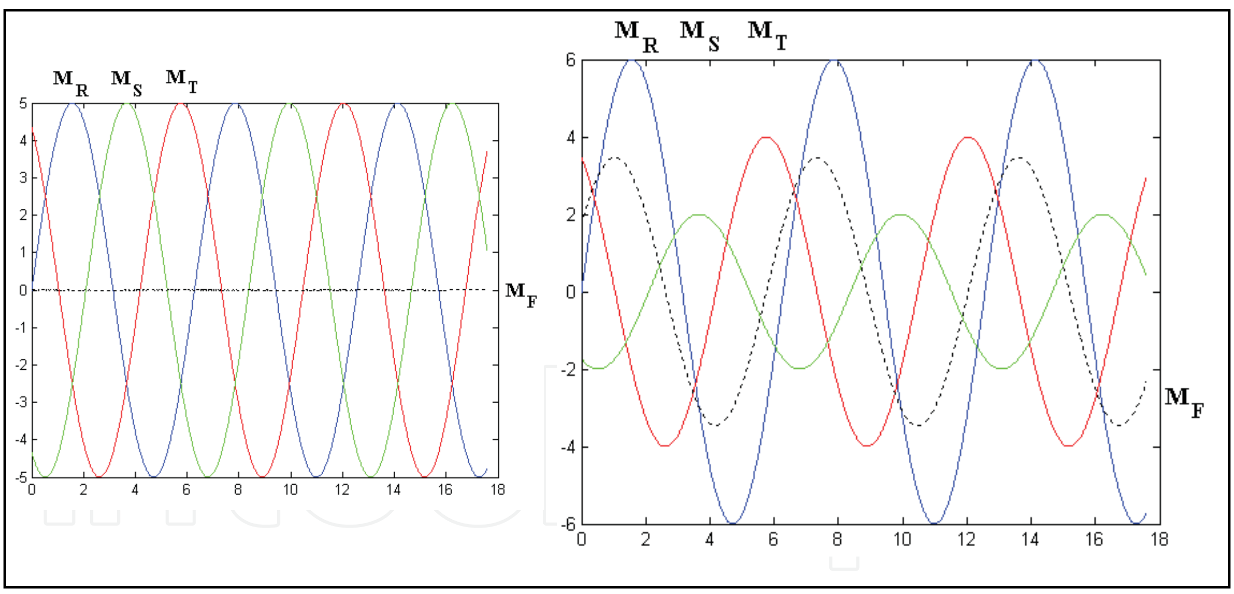

Fig. 1. Representation of sinusoidal ωt-dependent function of a balanced 3-phase system (left) and unbalanced 3-phase system (right).

The Figure 1, on the right, draws the sinusoidal ωt-dependent function of an unbalanced 3-phase system defined by:

$$M_R = 6\sin(\omega t - 0.5\pi/3)\,;\; M_S = 4\sin(\omega t - 1.8\pi/3)\,;\; M_T = 2\sin(\omega t - 5.4\pi/3)\,.$$

M_S is the vectorial sum of M_R, M_S, M_T phasors. The phasorial diagrams of these systems are depicted in Figure 2.

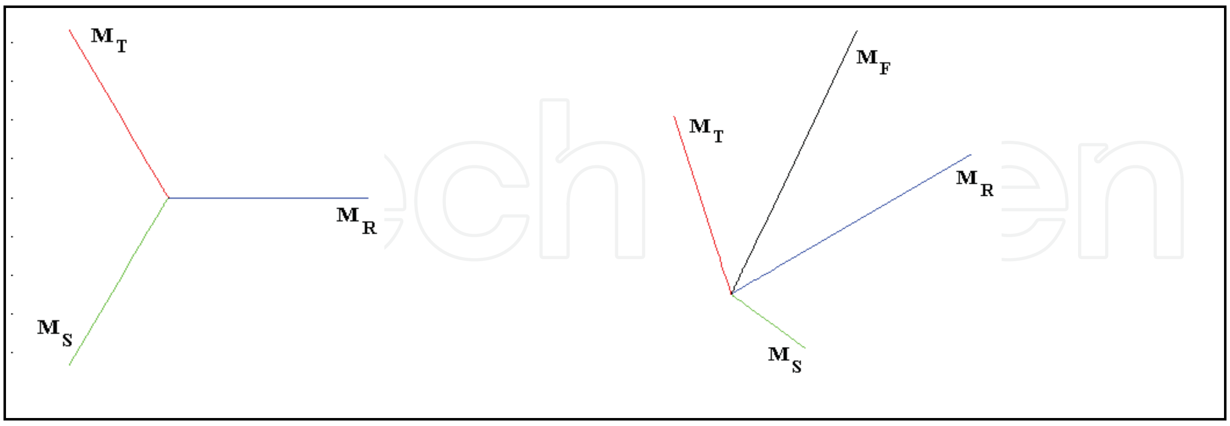

Fig. 2. Phasorial diagram of a balanced 3-phase system (left) and unbalanced 3-phase system (right)

One of the most important issues in the study and analysis of power systems refers to system failures, especially in the electrical transport system. A fault causes a failure on the system and, as a result, currents and voltages and other electric magnitudes usually become unbalanced. The failure analysis of power systems under faults uses the notion of symmetrical components, which helps to calculate the mathematical relationships between the values of phasors of unbalanced system .

The method is applied to the analysis of unbalanced systems to determine the symmetrical components of currents in the fault, and then find the currents and voltages at various points in the system. The most important application of symmetrical components theory is in 3-phase power systems, when it is necessary to simulate the dynamic response of the system due to faults, such as phase to ground, phase to phase, 3-phase short-circuit, and others. Besides, the symmetrical components theory gives clearer explanatios than others about many electrical phenomena, such as rotor heating in machines, neutral current and so on. The symmetrical components were introduced by Fortescue (Fortescue, 1918) to ease the calculations for unbalanced 3-phase systems. It uses the decomposition of the electrical variables, i.e. voltage and load current, into symmetrical components. The basic concept of this theory is to convert a set of three phasors into another set of three phasors with some desirable properties.

Acording to the symmetrical components theory, each one of unbalanced phasors can be decomposed into three balanced systems, known as the positive phase sequence (PPS), negative phase sequence (NPS) and zero phase sequence (ZPS), formed by:

▪ A balanced set of symmetrical components of positive sequence (direct sequence) that consists of three phasors of equal magnitude or module, displaced from each other by an equal phase of 120º and by a rotation as the original unbalanced set, i.e. RST, STR and TRS.

▪A balanced set of symmetrical components of negative sequence (reverse sequence) that consists of three phasors of equal magnitude or module, displaced from each other by an equal phase of 120º and by a rotation, opposite to the original unbalanced set, i.e. RTS, TSR and SRT.

▪A balanced set of zero sequence of 3- coincident phasors. The three ZPS phasors are equal in magnitude or module and are all in phase with each other.
There is a compact mathematical formula to write out the Fortescue theorem. Let suppose a balanced 3-phase system of phasors M_R, M_S, M_T. The letter ***a*** is to be used to denote the operator that creates a 120° anti-clockwise rotation. This operator is a complex number defined by the following terms:

$$a = 1\angle 120^{o} = -0.5 + j\frac{\sqrt{3}}{2} \tag{1}$$

Suitable operations with operador ***a*** gives the following operators:

$$a^2 = 1\angle 240^{o} = -0.5 - j\frac{\sqrt{3}}{2};\quad a^3 = 1\angle 360^{o} = 1\angle 0^{o} = 1;\quad a^4 = 1\angle 480^{o} = a;\ ....$$

Having in mind these operators, the phasors of a balanced three-phase system of positive sequence can be expressed by means of:

$$(M_{1R}, M_{1S}, M_{1T}) = (M_{1R}, a^2M_{1R}, aM_{1R}) = (1, a^2, a)M_{1R} \tag{2}$$

That is, the phasor M_{1R} denotes the set of phasors of a balanced 3-phase system associated to the positive sequence $(1, a^2, a)$. The phasors of a balanced 3-phase of negative sequence can be also expressed as follows

$$(M_{2R}, M_{2S}, M_{2T}) = (M_{2R}, aM_{2R}, a^2M_{2R}) = (1, a, a^2)M_{2R} \tag{3}$$

That is, the phasor M_{2R} denotes the set of phasors of a balanced 3-phase system associated to the negative sequence $(1, a, a^2)$. Finally, the sum of vectors of the three 3-phase systems of symmetrical components (zero, positive and negative) gives the original unbalanced 3-phase system. This can be mathematically expressed as

$$\begin{bmatrix} M_R \\ M_S \\ M_T \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} M_{0R} \\ M_{1R} \\ M_{2R} \end{bmatrix} \tag{4}$$

A simple matrix operation gives that the symmetrical component may be obtained from the original unbalanced vectors with the following equation:

$$\begin{bmatrix} M_{0R} \\ M_{1R} \\ M_{2R} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} M_R \\ M_S \\ M_T \end{bmatrix} \tag{5}$$

The Figure 3 depicts a Cabri-based applet prepared for the geometrical demonstration of Fortescue theorem. This geometric application made in Cabri allows the analysis of failures in electric power systems using the symmetrical components.

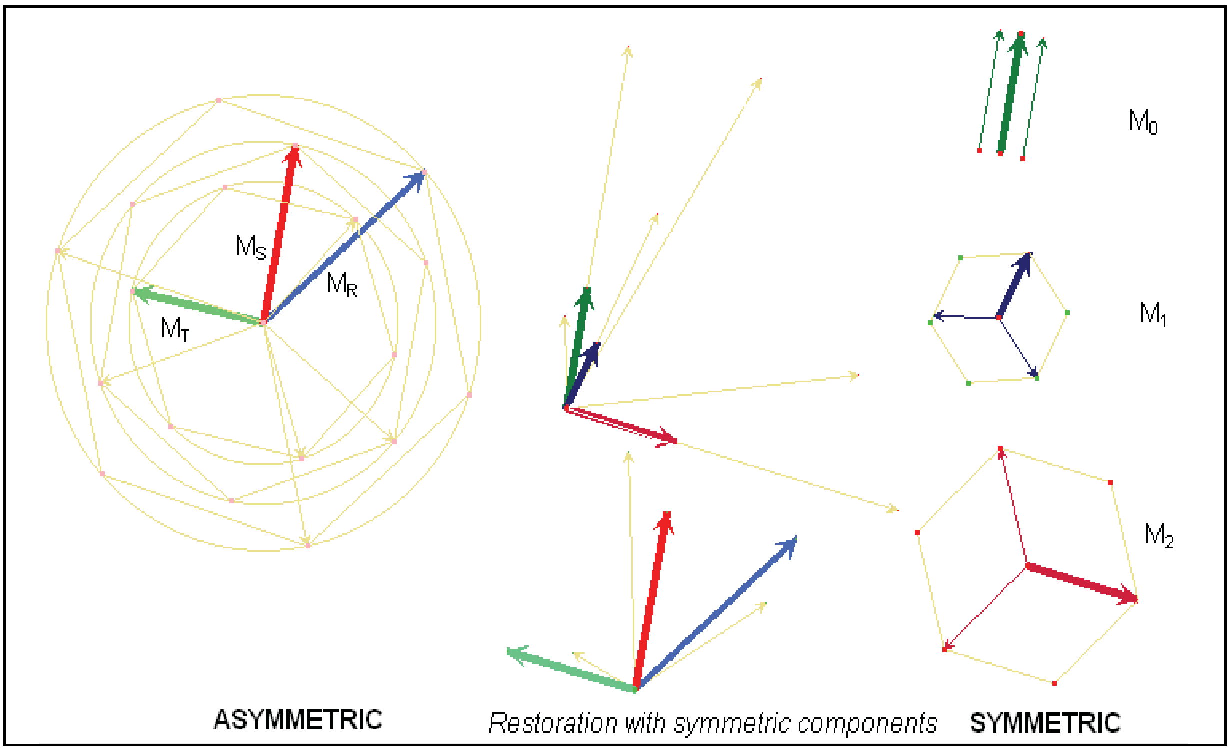

Fig. 3. Geometric analysis of symmetrical components of unbalanced 3-phase systems

On the left of the Figure 3, a phasorial representation of an unbalanced 3-phase system is drawn. The module of the phasors may be modified by changing the radius of the circle passing through the end of each vector and the direction of the vectors may be modified by moving the extreme point of each vector. The chart includes a procedure for obtaining the (1, a, a^2) sequence out of each vector. To this, it is drawn a regular hexagon inscribed in the circle that passes through the end of each vector.

With a simple geometrical procedure using the basic options in Cabri, sum of vectors and homotetic operation, it can be obtained the denoting phasors of the symmetrical components with zero, positive and negative sequence, respectively. The top center of the Figure 3 contains the geometrical design for the obtention of these vectors. With a translation of denoting phasors the equivalent 3-phase systems are drawn following similar procedure as in unbalanced system. The construction is depicted on the right of the Figure 3. At the bottom center of the figure is reconstructed the three-phase unbalanced system. The aim of the reconstruction is to check the validity of the formulas and that the procedure for the geometrical construction of symmetrical components has been correctly elaborated.

A particular case of unbalanced 3-phase system is generated by the phase to phase fault, which is one of the faults generally analyzed in textbooks. It is defined by the following condition: $M_S = M_T$. In this case, M refers to the voltage at the point of failure. A simple modification of the unbalanced 3-phase system in the Cabri applet is enough to check that $M_{1R} = M_{2R}$, the result that is also obtained by the mathematical analysis.

The Cabri applet gives more information, since it calculates the values of the modulus and direction of all the phasors, as well. It easily find solutions to all fault conditions and the analysis of system failures does not require a great amount of time.

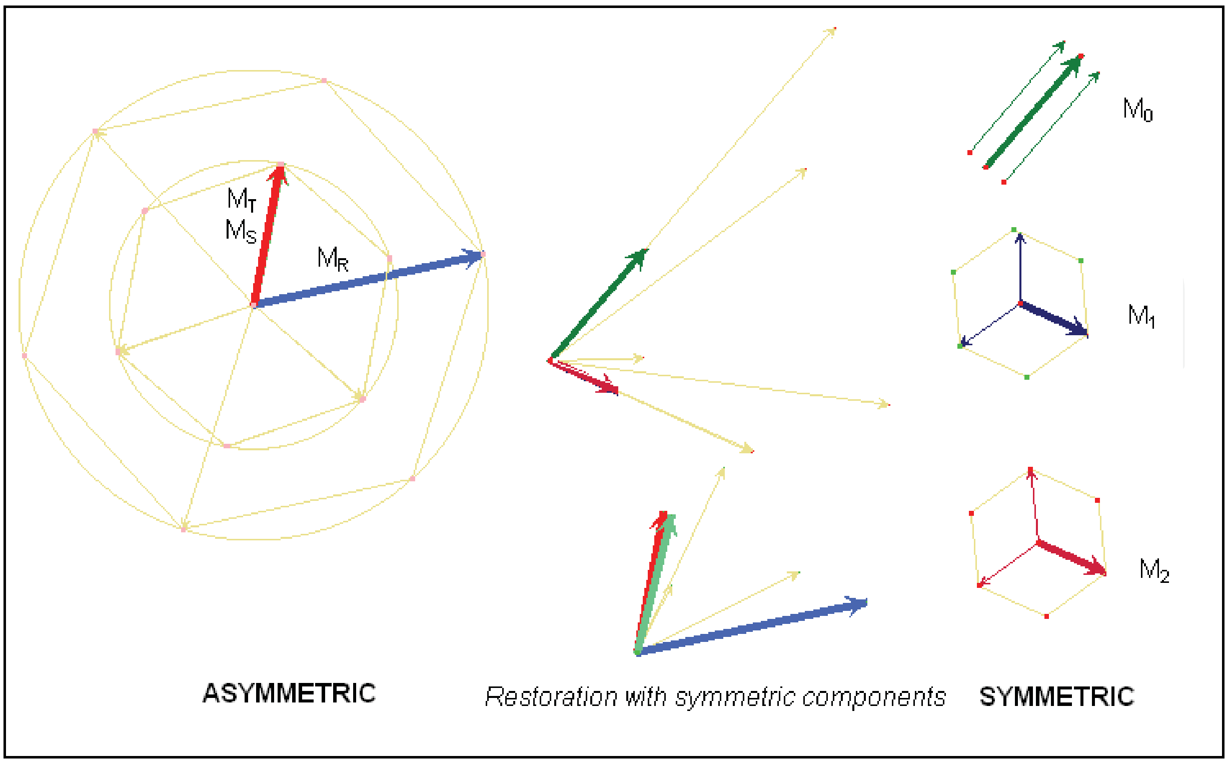

Fig. 4. Geometrical analysis of phase to phase fault in electric 3-phase systems.

4. Geometry in Automatic Control. A case

Control theory is usually divided in two parts: frequency domain and time domain. The study of controlled systems is often focused on the frequency domain for examining performance, stability and robustness of systems. Frequency domain techniques have been traditionally used to meet frequency domain specifications, such as gain and phase margins, which are traditional indicators of stability and robustness. Other authors have proposed techniques in the time-domain to meet damping factor and overshoot, which are alternate indicators. Undergraduate students learn much about some of these techniques for processes without time delay. However, processes with dead time are rarely considered in textbooks, since the equations related to them are highly nonlinear and analytical methods of analysis or design are not yet available (Ästrom & Hägglund, 2001).
In the frequency domain, many techniques take into account the Nyquist diagram to analyze properties of controlled systems. The drawback of working with the Nyquist diagram is that, besides the information about the stability of the system, it only provides information about the properties in the frequency domain. The system properties in the time domain are usually related to some points in the Nyquist diagram, which are obtained from heuristic procedures. This implies a high degree of inaccuracy and uncertainty. On other hand, the temporal properties of the system when time $t \to 0$ are related to higher frequencies, obtaining the value of the response when $\omega \to \infty$.
However, the Nyquist diagram delineates only the representation for the initial frequencies, which provide information about the behavior of the system in the time limit, to say, the stationary behavior of the system $t \to \infty$ is obtained for $\omega \to 0$.

It may be of great interest to find a diagram that can provide full information about behavior and properties of a system. This section offers a geometrical procedure to represent any response in a plane using the inverse modulus of open- and close-loop transfer functions. This representation can be related to second-order responses of specific overshoot, which is determined by the damping factor ξ. This representation correlates properties both in the frequency and time domains.

4.1 Damping factor curves and inverse of modulus representation

Model-based approaches are frequently used to simplify controller design process. They work under the assumption of a desired response closed-loop transfer function from input to output. The response of controlled plant may be modelled by a second-order plus time delay (SOPTD) in many industrial applications. The transfer function of system of a desired SOPTD response is:

$$H(s) = \frac{\omega_n^2 e^{-t_d s}}{s^2 + 2\xi\omega_n s + \omega_n^2} = \frac{e^{-t_d s}}{\alpha s^2 + \beta s + 1} \tag{6}$$

where s is the Laplace operator, $\alpha = 1/\omega_n^2$; $\beta = 2\xi / \omega_n^2$ and $\xi = \beta^2 / 4\alpha$.

The open-loop frequency response of model (6) is

$$L(j\omega) = \frac{e^{-j\Theta}}{1 - \alpha\omega^2 + j\beta\omega - e^{-j\Theta}} \tag{7}$$

where $\Theta = \omega t_d$. The modulus of L(jω) is

$$\left|L(j\omega)\right|^2 = \left[\left(1 - \alpha\omega^2 - \cos\Theta\right)^2 + \left(\beta\omega + \sin\Theta\right)^2\right]^{-1} \tag{8}$$

Applying the following definitions

$$x = \beta\omega \; ; \; y = 1-\alpha\omega^2 \tag{9}$$

the equation (8) can be transformed into

$$\left(x + \sin\Theta\right)^2 + \left(y - \cos\Theta\right)^2 = \frac{1}{\left|L(j\omega)\right|^2} \tag{10}$$

Equation (10) is a conic formula which describes a circle with radius $1/|L(j\omega)|$ centered at point (-sin Θ, cos Θ). It can be also demonstrated that the inverse of closed-loop transfer function $|H(j\omega)|$ is equal to the distance of point (x,y) from (0,0). and is equivalent to the value $|D|/|L|$, where D es the distance to the critic point (-1,0) in the Nyquist diagram. Rearranging equation (9), it is obtained that

$$y = 1 - \frac{x2}{4\xi^2} \tag{11}$$

It may be depicted the curves of equation (11) in a plane for different values of relative damping ξ ranging from zero to ∞, as shown in Figure 5, on the left . In the same plane, it can be depicted the circle described by different values of Θ, as in the center of Figure 5, and a joint representation of equations (10) and (11) may be as in Figure 5, on the right. It is easy to find that a point (x,y) in this curve is related to the triangle [unity radio, inverse of modulus of the open-loop (1/L leg), inverse of modulus of closed-loop (D/L leg)] defined by a specific value of Θ. The unit leg of this triangle makes an anti-clockwise rotation linked to the value of Θ.
The Figure 5 , on the right, shows the diagram obtained forf a SOPTD response when ξ=0.7. It is also shown the curve of a first-order plus time delay (FOPTD) response as a limit of SOPTD ξ=∞.

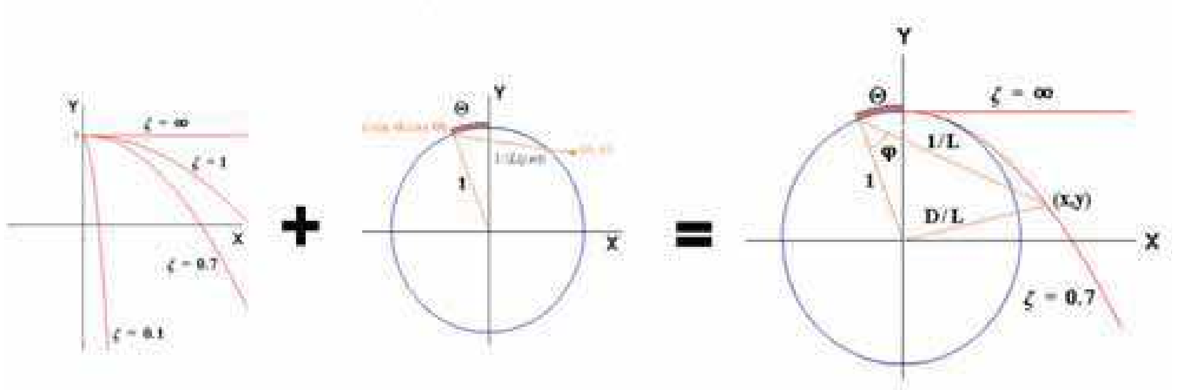

Fig. 5. Diagram of the inverse of modulus and damping factor of SOPTD responses

Notice that the argument of the open-loop response is measured by the angle between the unit and open-loop legs. The argument of the closed-loop response is measured on the central point (0,0) by the angle of the triangle formed with vertical axis and the closed-loop leg D/L.

4.2 Generalization to controlled systems

Consider a plant described by the transfer function G(s) and controlled by a controller C(s)

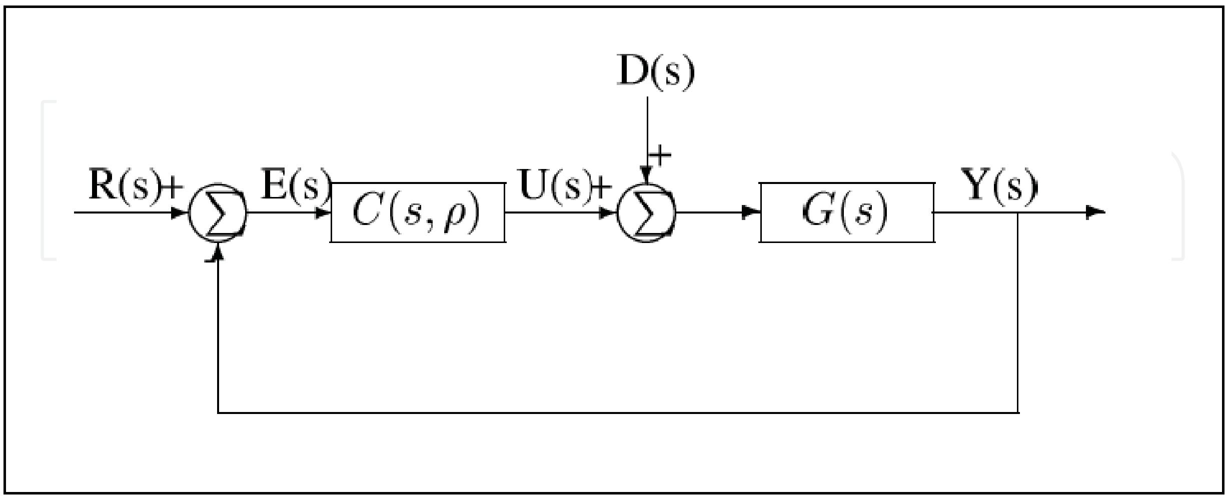

Fig. 6. Conventional SISO controlled structure

For the system in Figure 6, the closed-loop response upon set-point change is

$$H(s)=\frac{C(s)G(s)}{1+C(s)G(s)}=\frac{C(s)G_r(s)e^{-t_d s}}{1+C(s)G(s)}=\frac{e^{-t_d s}}{1+\frac{e^{-t_d s}}{C(s)G_r(s)}} \qquad (12)$$

The equation (12) is similar to equation (6) if $e^{-t_d s}[C(s)\ G_r(s)\ ]^{-1} = \beta_\Theta s + \alpha_\Theta s^2$. This is generally possible in the frequency domain provided that $t_d \neq 0$. Let define ξ^2_Θ as

$$\xi_\Theta^2=\frac{\beta_\Theta^2}{4\alpha_\Theta} \qquad (13)$$

Applying the following definitions

$$X_\Theta=\beta_\Theta\ ;\qquad Y_\Theta=1-\alpha_\Theta\omega^2 \qquad (14)$$

and operating with equations (12), it is obtained the general equation

$$Y_\Theta=1-\frac{X_\Theta^2}{4\xi_\Theta^2} \qquad (15)$$

The formula of this equation is similar to (11). Though its representation in a plane may be a complex curve, the formulation may be functionally considered as a ξ-curve. For each value of ω , that is Θ, there is a ξ-curve that coincides with the complex curve. This complex curve of equation (15) may be characterized by the dominant ξ-curve, which is generally denoted by the lower value of ξ_Θ. Therefore, any controlled system may be analyzed under the point

of view of its dominant SOPTD ξ-curve. Innovation of this diagram is that combines time and frequency domains and that depicts main properties of open- and close-loop transfer functions. The main features of dynamic behavior for any transfer function may be also obtained with this diagram.

4.3 Geometrical analysis of main properties of SOPTD responses

Phase margin (Φ_m). From the basic definition of phase margin, the following equation is obtained.

$$\begin{aligned} &\left|L(j\omega_g)\right| = 1 \\ &\Phi_m = \varphi_p = \arg\left(L(j\omega_g)\right) + \pi \end{aligned} \qquad (16)$$

where ω_g is known as gain crossover frequency. For a given value of ξ, each point of ξ-curve fixes a value of Θ_g at a distance of one unit length. Given a choice of Θ_g and solving the system (10) and (11) for particular values of (x_p, y_p), it is obtained the relations between phase margin, the relative damping ξ and the feasible values of Θ_g. Figure 7, on the left, shows the construction of the phase margin in the proposed diagram.

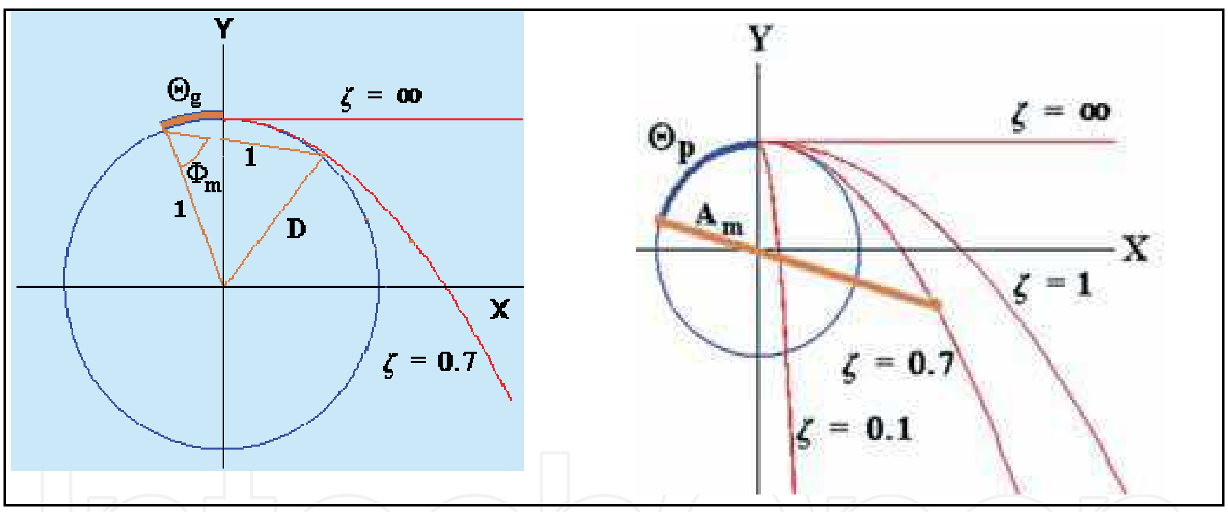

Fig. 7. Geometrical procedures for the obtention of Phase and Gain margins

Gain margin (A_m). The definition of gain margin gives

$$\begin{aligned} &A_m = \left|L(j\omega_p)\right|^{-1} \\ &\varphi_g = \arg\left(L(j\omega_p)\right) + \pi = 0 \end{aligned} \qquad (17)$$

where ωp is known as the phase crossover frequency. The gain margin point at the ξ-curve is (xg, yg). The stability conditions of the SOPDT response only are satisfied when

$$x_g = \rho \sin \Theta_p$$
$$y_g = \rho \cos \Theta_p \qquad (18)$$

where ρ= A_m-1 is the radius of the circle which meets the ξ-curve at the point (x_g, y_g).

Robustness. The point (0,1) in the proposed diagram has significant properties. This point indicates the ideal performance of response, because α= 0 and β = 0. The point (0,1) denotes the convergence point of all SOPTD and FOPTD responses. Then, the objective of controlled systems might be to achieve this ideal point, or a close point, for the frequency of phase margin. However, it also can be observed that there is no change of phase margin limit (60º) modifying ξ and that solutions of (x_p, y_p) around (0,1) have no robustness, since minor changes in the system parameters will carry it to instability.
In a practical situation, it is necessary to decrease the value of phase crossover frequency Θ_g to achieve acceptable performance robustness. It is of common sense to place Θ_g far from π/3 at least at a point which matches the minimum time delay margin. Then, the response becomes slower and robust. To avoid problems of robustness and achieve the quickest response, it must be selected the point of phase margin in the specified ξ out of the limits of a circle r centered at point (0,1). Hence, a coefficient of robustness may be defined as

r = distance to point (0,1) (19)

In Figure 8, the point (x_r, y_r) may provide sufficient robustness against expected changes in time delay and parameter values of a controlled process.

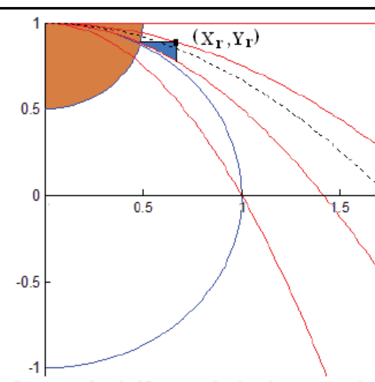

Fig. 8. Robustness against changes in time delay and parameters of a controlled process.

Overshoot. The overshoot OS for a desired closed-loop response can be obtained with

$$\ln OS = -\frac{\beta\pi}{2\alpha\omega_d} \qquad (20)$$

Generally, a limit of the achievable maximum overshoot is specified in industrial applications. It is well known that the maximum percent overshoot will increase with decreasing ξ. For a second-order response, the relative damping ξ formula results from equation (11) and (12)

$$\xi^2 = \frac{\beta^2}{4\alpha} = \frac{\ln^2 OS}{\ln^2 OS + \pi^2} \tag{21}$$

This formula relates the OS and ξ . The curve ξ denotes points of equal overshoot. The lower of ξ, the greater overshoot.

4.4 CABRI-based representation of SOPTD responses

A Cabri graphical procedure is prepared to obtain the solution for a SOPTD that matches requirements. The construction of the geometrical procedure is shown in Figure 9.

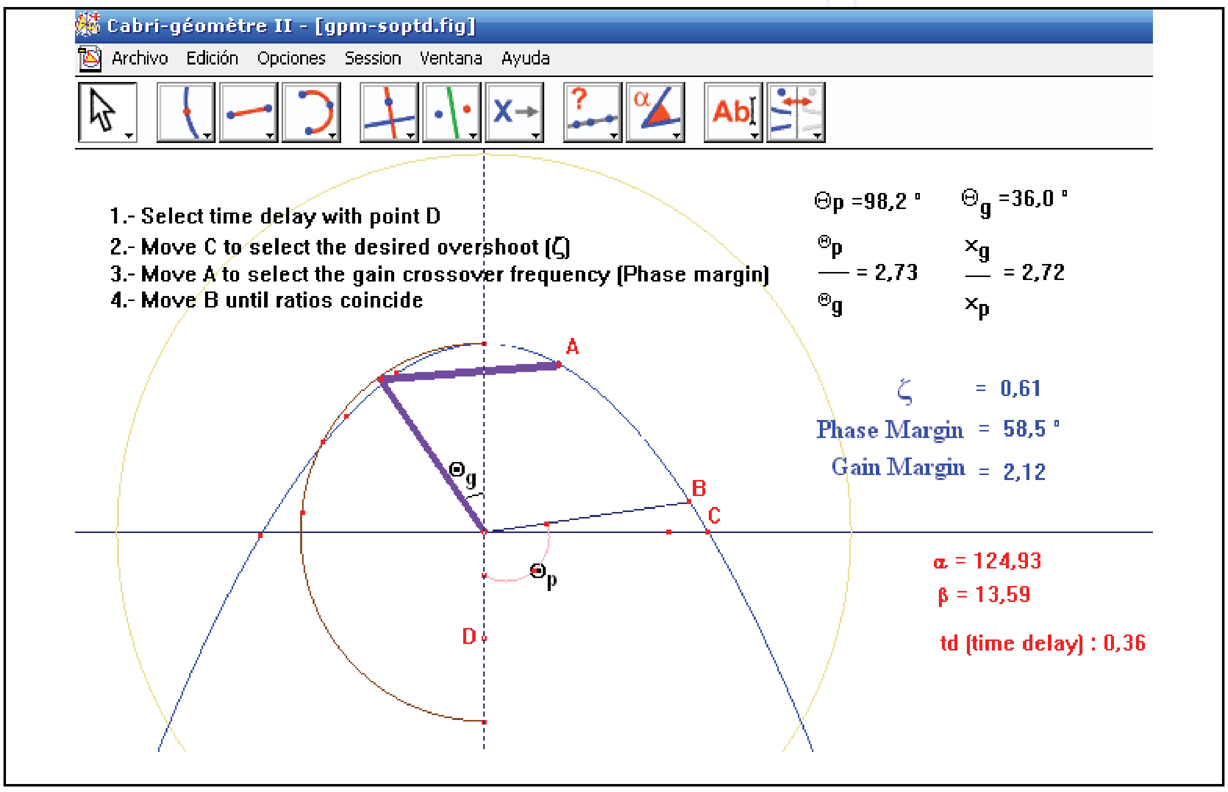

Fig. 9. Dynamic representation of ξ curves and inverse modulus with Cabri

The procedure is handled in four steps: Moving the point D is selected the time delay of response. Move C to select the desired overshoot, that is ξ . Move A to select the gain crossover frequency. Move B until ratios Θ_p/Θ_g and x_g/x_p coincide (condition of gain margin). With this condition, the solution of gain margin is obtained for a selected Θg. The exact values of gain and phase margins are displayed. Generally, the recommended range of gain margin is between 2-5 and the recommendation for the phase margins range is between 30-60º.

The use of a combined chart of frequency- and time-domain properties for a response can help designers to select adequate specifications of response. In a practical situation, the goal of design is to achieve acceptable performance while assuring stability. The goal of controller design might be to achieve the quicker and robust response without oscillations. Since performance depends on the type of controller and its tuning, controller design starts

from performance specifications. However, the criteria for setting specifications are normally based on empirical considerations. The application of CABRI-geometry may help to set adequately specifications.
The use of a combined chart of frequency- and time-domain properties for a SOPTD response can help designers to select adequate specifications. Usually, these specifications are set from empirical considerations. The Cabri diagram can be used in order to foresee the behavior of a controlled system. It also provides clearful explanations about some rules-of-thumb of controller design. The CABRI applet may be seen as a simple and easy pedagogical tool to analyze real systems.
From the graphical representation comes up the importance of an adequate selection of phase crossover frequency. The rest of performance properties in both domains hold on that choice. Working with the CABRI applet, it is illustrated the interdependency between different specifications. It has been also shown how many specifications are set without consistency, more often than not. Thus, students and operator can learn to discriminate good or bad design rules.

5. Animation in Textbooks

In the multimedia era, there has been a renovation in publication. This has occurred in many areas, such as newspapers, the academic world and in education. In this, contents such as animations, videos, and interactive demonstrations, are provided to students on CD-ROMs, DVDs, Blue-ray disks as part of textbook packages. This way, it is pointed out that students would be able to learn and memorize the concept much faster.
The animated textbooks will have motion in pictures of various concepts that have been traditionally explained by diagrams. The concept of the symmetrical components, for example, would be explained by an animation of the phasors rotating with ωt. In electrical power systems, animations would also be provided for various topics related to phasors (phase, amplitude and initial phase). Similar animations would be prepared for various concepts in science themes and for those in technology
The pages of the animated textbooks will also contain links to web sites related to the subject matter being explained in them to encourage students to explore the subject outside of their textbooks.
To date, these enhanced media have not been fully integrated into a self-contained textbook format. Instead, student are required to operate leaving the text to read a CD-ROM, DVD, download movie, open a Web link, and so on. These activities would all seem to distract from the continuity of an integrated educational experience—an actual enhanced, interactive textbook.
The Portable Document Format (PDF), developed by Adobe Systems Incorporated has become a de facto standard for digital publication. One of the main advantages of PDF is that documents are easily transferable between different operating systems, PDF files may be produced from a range of publishing packages in personal computers, along with free applications like LaTeX. Adobe Acrobat 3D Version 8 enables the inclusion of interactive figures within PDF documents, that other free packages have previously resolved for LATEX.
The LATEX *movie15* package (Grahn, 2009b) provides an interface to embed movies, sounds and 3D objects into PDF documents for use with LaTeX as well as pdfLaTeX. The

specification allows media file data to be completely incorporated into the PDF output, thus producing self-contained PDF documents. The LATEX *animate* package (Grahn, 2009a) provides an interface to create PDFs with animated content from sets of graphics or image files, from inline graphics, such as LATEX-picture PSTricks or just from typeset text. Unlike standard movie/video formats, package *animate* allows for animating vector graphics. The result is roughly similar to the SWF format. Thus, geometric animations may be included in textbooks.

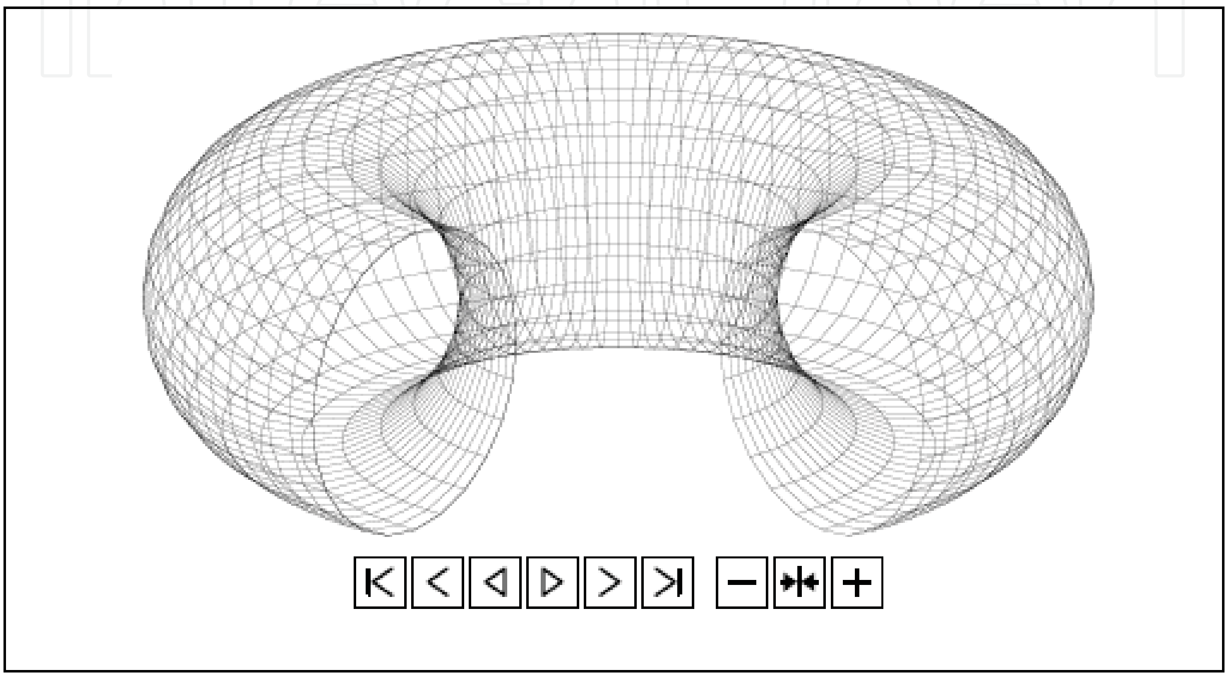

Fig. 10. Torus section created with LATEX animate package

The introduction of Geometry means that the theoretical explanations can be simple and affordable for both the teacher and the students, and proves the advantages of simplicity, continuity, understandability and extensibility in learning and teaching. Students explore dynamic illustrations, they develop ideas and find their own solutions for a given problem.
This way of working supports autonomous and cooperative learning of technology at university. It encourages an active discovering approach to technological thinking. Students are more deeply involved in the process of finding and solving technological problems. This leads the students to increased activity and better understanding of new technological situations. The animation in textbooks also emphasizes the integration of interactive multimedia technology into the process of learning and teaching.

6. Conclusion

The practice of mathematics in the world outside education has changed considerably as a result of the development of powerful software tools. In general, however, little attention has been paid to Geometry. It has been demonstrated the convenience of Geometry for learning and teaching of tecnological matters in high level courses. The theoretical background of subject matters includes copious formulas that have a strong geometric

understanding. Two representative examples have been provided to exemplify the use of Geometry in teaching Tecnology with different strategies. In both cases, the use of geometrical models makes easy the apprehension, understanding and learning and avoids some of drawbacks encountered in most of sophisticatedl educational software.
Through accessible examples we have tried to give a concise view of just how IGS software tools could impact on an up-skilling technology by making more stimulating lectures and animated textbooks. A wider range of examples of such strategies is needed, besides an encouragement for more people to be involved in developing them.

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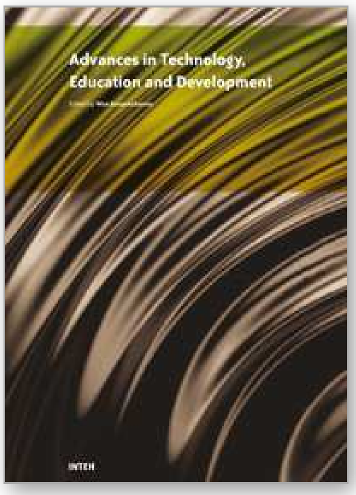

Advances in Technology, Education and Development

Edited by Wim Kouwenhoven

ISBN 978-953-307-011-7
Hard cover, 474 pages
Publisher InTech
Published online 01, October, 2009
Published in print edition October, 2009

From 3rd to 5th March 2008 the International Association of Technology, Education and Development organised its International Technology, Education and Development Conference in Valencia, Spain. Over a hundred papers were presented by participants from a great variety of countries. Summarising, this book provides a kaleidoscopic view of work that is done, all over the world in (higher) education, characterised by the key words ‘Education” and ‘Development’. I wish the reader an enlightening experience.