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Teaching Electric Circuit Theory with the Help of Tutorial Software

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The development of computers has dramatically influenced modern teaching technologies. The first part of this paper considers the problems and advantages of computer-aided teaching. In the second part a project concerned with computer-aided teaching of Electric Circuit Theory (ECT) is outlined and illustrated with several examples from the Department of Theory of Electrical Engineering at the University of West Bohemia, Czech Republic.

INTRODUCTION

Electric Circuit Theory (ECT) has been a fundamental component of the teaching of electrical engineering since the dawn of university electrical engineering studies at the beginning of this century. In reflection of developments in the USA it was later introduced as an independent subject in most faculties of electrical engineering. Highly developed and deeply considered methods of pedagogical presentation, including excellent textbooks, examples and other teaching aids, have emerged in the long-term development of this field of science.

There is clearly an important role for contemporary computer science in the teaching of technical disciplines, including ECT, but this does not simply suggest an *improvement* of hitherto used teaching methods: in many instances it is necessary to rebuild these methods from the ground up. In fact it could be observed that the existence of a well developed *classic* pedagogical system in the teaching of ECT, one that has proven with time to be effective, and the necessity to undergo a revolutionary conversion of this system in order to adopt a modern computer-based teaching technology might be factors in the fairly slow introduction of computer-aided teaching in this discipline. The same situation can be found in other theoretical disciplines of electrical engineering.

This paper considers this situation, the advantages and shortcomings of both teaching approaches, and suggests that a good teacher will be unable to ignore the considerable efficiencies of modern conceptions and will thus consistently support and introduce them.

NEW EDUCATIONAL TECHNOLOGIES

The method for solving a technical problem is very dependent on the tools that are available. When the only tools available were tables of various transcendental functions and a logarithmic slide rule, the preferred analytical methods were those which enabled the discovery of a solution in a closed form. Often certain approximations were applied that led to approximate solutions whose exactness was acceptable only within a certain region of input parameters. The subsequent development of computers created a need for a theory to formulate the algorithm of calculation for which application programmes could be made. Initially computers were applied to solving the system of equations numerically, to which end various iterative and recursive numerical methods were used; with time the programmes were perfected so that they could generate a mathematical model of the solved system.

The situation has changed dramatically during the last decade, which has been characterised by further rapid developments in the field of PCs, particularly in terms of computer networks and a wide range of tutorial software. The latter is offered with a wide spectrum of graphical representations of studied dependencies, and work with computers is becoming more interactive in character. The issues of numerical methods that used to be connected with often demanding problems of convergence and the stability of calculation processes, as well as constructing individual programmes, have given way to a single question: *what adequate strategy and method should be chosen for the implementation of a concrete project?*

The new calculation tools that are available nowadays have dramatically influenced the possibilities of educational technology. The work of a teacher who chooses to stick with the *classical* methods of teaching and not to use these new tools would necessarily be marked by the following shortcomings:

- Students would be acquainted with outdated and less effective methods and procedures. In the *classic* method of study a student must overcome the difficult barriers of mathematics, which makes the subject very unattractive.
- The educational process also usually implies issues that have only secondary importance for reaching the given objective. There are for example various alternative methods for finding solutions to concrete problems that differ only in the laboriousness of calculations, but when using the computer these differences are negligible; or there are recapitulations of subsequently needed parts from mathematical analysis or numerical analysis. Without computer-aided teaching, all this considerably diminishes teaching time that could otherwise be used for extending and intensifying the subject or for decreasing the number of lessons.
- Students will not foster a philosophy of thinking that is necessary for the full use of contemporary computer equipment.

There are many reasons why education is not implemented in compliance with the contemporary state of computer science, and an attempt to describe them follows.

The development of computers and tutorial software is, and has been, rather rapid and many teachers who are used to older teaching styles and paradigms find it difficult to adopt computers in their teaching. Some defend themselves with the disputable argument that they do not want their students to become brainless computer attendants.

At the same time it is necessary to admit that the commercial education software on offer in the Czech Republic is inadequate. The tutorial software that is available has, from the pedagogical point of view and sometimes also from the factual point of view, various shortcomings. In educational technology, only such software that enables the quick solution to a wide range of complicated problems, that its user can master in a short time and that does not require a lot of specific knowledge can be used.

In the *classical* pedagogical process students have been acquainted in some detail with the physical laws, their mathematical formulation and, with the help of analytical and numerical methods, also with their use, so that all this effort could be accomplished by the numeral calculation, with the use of a computer only for some partial operations. This complicated and difficult way of teaching has its pedagogical traditions. A student that is able to work through this penetrates with detailed understanding to the principle of the solution (often in more than one way). They may very often lack the endurance or time for the physical interpretation of the results however, not to mention the repetition of the calculation, which is quite often necessary for various reasons. Tutorial software offers a substantial short-cut, enabling the student to solve even complicated tasks relatively quickly, relieving the student of their fear of difficult and boring calculations, and providing them with sufficient space for the discussion of the results. As the solution can be reached quite easily, the user does not oppose the modification of the task, the repetition of the calculation and sometimes finding the optimal solution.

Tutorial software that is a reliable support in pedagogical practice is required:

- to enable fast and easy setting of input data (refusal of nonsense data, the possibility of checking the data and changing them etc);
- to have a high comfort of attendance (communication with the user through menu and sub-menu, mouse control etc);
- to communicate with the user in the language of the user; the manual must also be intelligible as language obscurities weaken the attention of students and can be a source of mistakes;
- to provide good graphics; results gained in a numerical form only are not practical.
- to enable easy printing of the document (set, results, graphs etc).
- have appropriate universality (either too universal or too simplified, a *school* version, is unsuitable).
- to be available for the students (eg in the computer network of the university).

It is necessary to accept that tutorial software originating in other countries typically uses symbols and signs that are not common in this country and do not match our standards.

PROJECT FOR THE TEACHING OF ELECTRIC CIRCUIT THEORY WITH COMPUTER ASSISTANCE

Proposal for the general syllabus of the subject *Theory of Electric Circuits*

When constructing the syllabus for ECT it is necessary to keep in mind both the level of knowledge acquired by students through prior studies, as well as studies which are to follow the course and to which ECT will be applied. This question is not to be discussed here and the educational model that is defined by the current curricula of the Faculty of Electrical Engineering of the West Bohemian University in Pilsen (Czech Republic) will be the point of departure for this work.

The syllabus of ECT implemented with full computer assistance starts from these premises:

- The main pedagogical aim of ECT is to impart knowledge about the *qualities* and *behaviour* of various kinds of circuits, while the physical processes that occur in electric circuits are stressed. Physical interpretation of ECT issues relies on the theory of electromagnetic fields and examines the changes of various working states of electric circuits. On the basis of this *physical behaviour* the ability to predict the *qualities* and *behaviour* of electric circuits in various working operations is fostered.
- Explications in the subject ECT are systematically linked with various applications from the subject Electrical Measurement that are realised through various simulated computer models.
- Commentaries on mathematical analysis and numerical mathematics that are common in the classic explications are excluded. Students are supposed to have a reliable tool for implementation of particular mathematical operations and the mechanism of the particular is not dealt with, unless the partial results have any important interpretation in electrical engineering (eg the knowledge that the particular solution of linear differential equations describing the circuit is the solution of this circuit in steady state.) In this way a significant amount of time is saved.
- While the *classic* pedagogical explication of ECT established a sharp distinction between linear and nonlinear circuits and then, almost without exception, specialised, above all for reasons of time, in linear circuits only, the explication with the assistance of commercial software is done in a more general conception, linked with a more profound view of the nonlinear phenomena in circuits. It is, for example, possible to compare the qualities of both types of circuits.
- Traditionally taught alternative methods for the setting of various mathematical models for analysis and synthesis of circuits barely differ from the point of view of numerical calculations done on the computer. Regarding the required continuity with the hitherto explication it, is not suitable to exclude these alternative methods, but it is necessary to assign less importance to them. This again results in the saving of time.

Basic course

- Electric circuits and their physical principles;
  - The physical and topological structure of circuits;
  - Kirchhoff´s Laws.
- Phasor representation of sinusoidal functions.
- Linear and nonlinear circuits in DC (Direct Current) and AC (Alternating Current) operation;
  - Resonance;
  - Superposition;
  - Thevenin/Norton Theorem;
  - Analysis/synthesis.
- Linear and nonlinear circuits in TA (Transient Analysis) operation.

Advanced course

- Two-port networks.
- Transmission systems of power engineering;
  - Three-phase circuits;
  - Transmission of power in sinusoidal and non-sinusoidal systems.
- Circuits with distributed parameters;
  - Uniform line in AC and TA operation;
  - Surge and wave phenomena in circuit systems.
- Parametrical circuits.

The described syllabi, implemented with computer assistance, have the following advantages:

- They stress the physical interpretation of the behaviour of the circuits and free the student from complicated and demanding mathematical calculations. As well as the pedagogical effect, this also contributes to the increased attractiveness of ECT.
- They stress the integrity of ECT with other subjects, especially subjects such as Systems Theory, Electromagnetic Field Theory and Electrical and

Electronic Measurement.

- It is possible to decrease the number of classes or, with the same number of classes, to enrich them by adding new parts. Computer conception also enables an easy differentiation of methods of teaching ECT according to specialisation and professional realisation. It is, for example, possible to apply ECT to the teaching of staff operating electrical equipment or to designers or research workers etc.

EXAMPLES FROM ECT WITH THE HELP OF TUTORIAL SOFTWARE

Transient Analysis

- For a linear circuit with lumped-parameters RC with non-zero initial condition $u_C(0)$ the response $u_C(t)$ is calculated by the TINA programme (Figure 1). In this case the student can easily check that the programme works as the analytical solution is known:

$$u_C(t) = U_0 \{1 - \exp(L\ t/R)\} + u_C(0) \exp(L\ t/R)$$

- For a nonlinear circuit RC with a diode, the response $u_C(t)$ is calculated by the TINA programme for various values of initial condition (Figure 2). A student can in this way check that the response is substantially dependent on the initial condition $u_C(0)$.

- With the TINA programme it is easy to identify the behaviour of any response with a changeable value of an element. In Figure 3 the responses $u_C(t)$ for various values of resistance *R* <100 W, 1k W > are shown.

- In Figure 4a a transmission line is shown in which a short-circuit occurs in the time $t = t_s$; it is modelled by the switch S_1. In the time $t_v > t_s$ the affected part of the transmission line is disconnected by the switch S_2. We are looking for current and voltage responses on the transmission line, and are modelling the transmission line as a ladder network composed of P-section, according to Figure 4b. This is a rather complicated transitive phenomenon in an electric circuit with six energy-storage elements. It is impossible to implement an analytical solution in the teaching process because of its complexity and time consumption, but it is possible to get the solution very quickly with the help of the TINA programme; by changing the parameters of an electric circuit it is possible to get any current and voltage response (Figure 4c).

Steady states

- The TINA programme can easily implement the total analysis of linear circuits, but also partial analysis eg with the help of Thevenin/Norton Theorem. In Figure 5a there is a resistance circuit in which we are looking for the voltage across the load re-

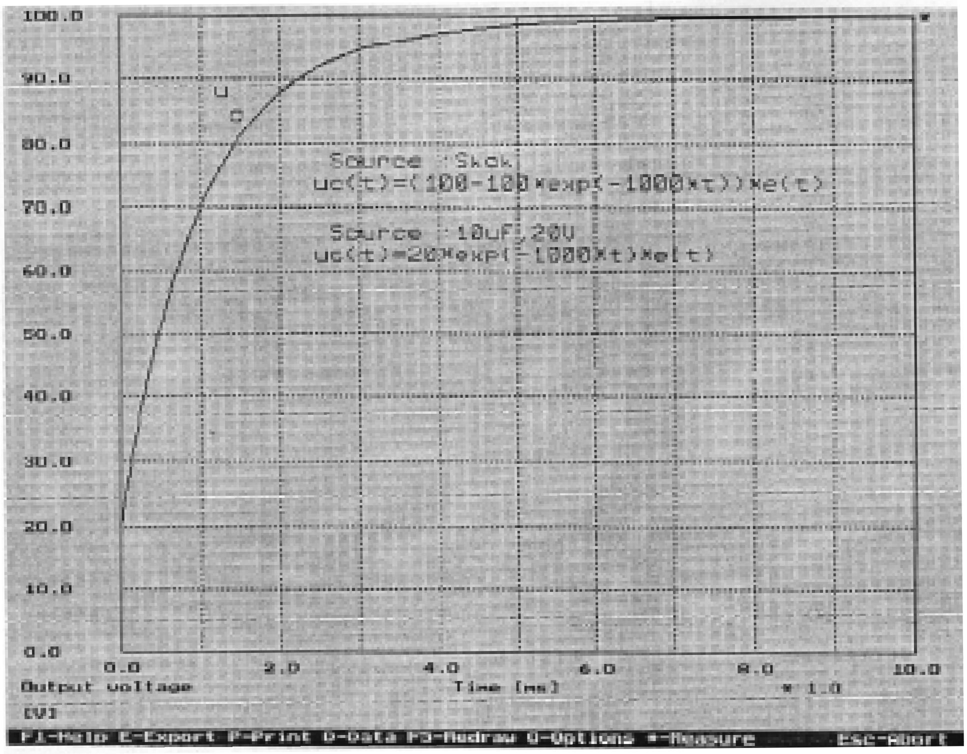


Figure 1: Voltage response of the capacitor in the linear series circuit RC.

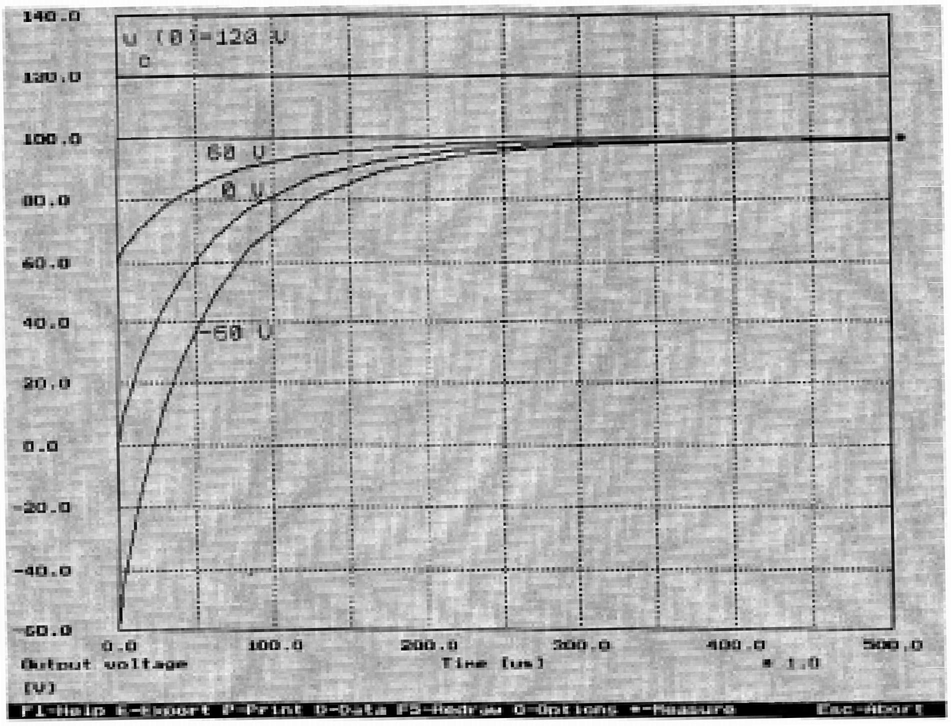


Figure 2: Response $u_C(t)$ in a series non-linear circuit RC for four values of the initial condition: $u_C(0)$ = - 60 V, 0, 60 V, 120 V.

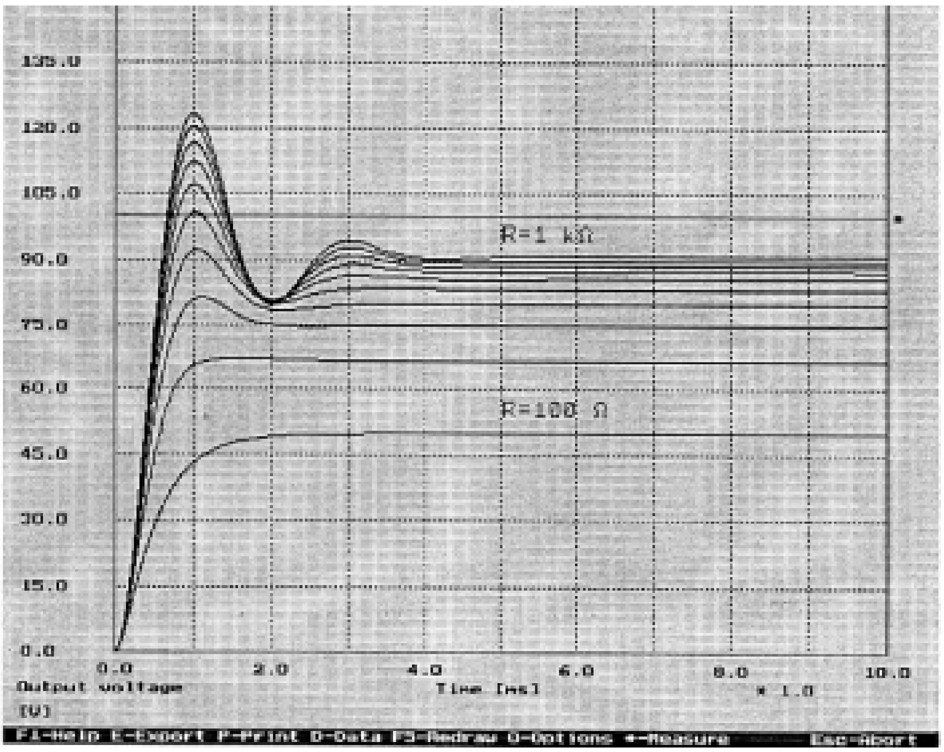
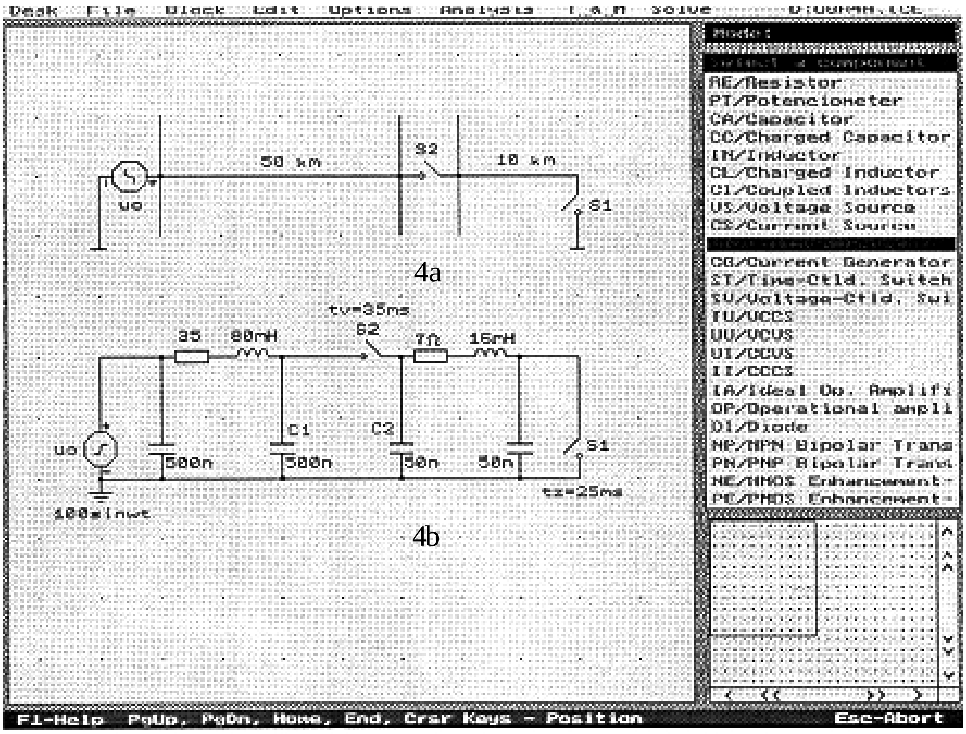


Figure 3: Courses of responses $u_C(t)$ for various values of parameter R <100 W, 1k W >.

sistance R_l. First we measure the Thevenin's equivalents of electric circuit, ie the voltage U_e (Figure 5b) and the resistance R_e (Figure 5c). The solution with the help of an equivalent electric circuit is then easy: U_{Rl} = 7.5 V. The same procedure can be used with AC circuits.

Simulated measurement in electric circuits

- Some programmes also have the function of a generator of voltage of various time courses and digital multimeter that enables the measurement of voltage, current, resistance and frequency in both



Figures 4a and 4b: Course of voltage before and after the switch that disconnects the transmission line affected by a short-circuit.

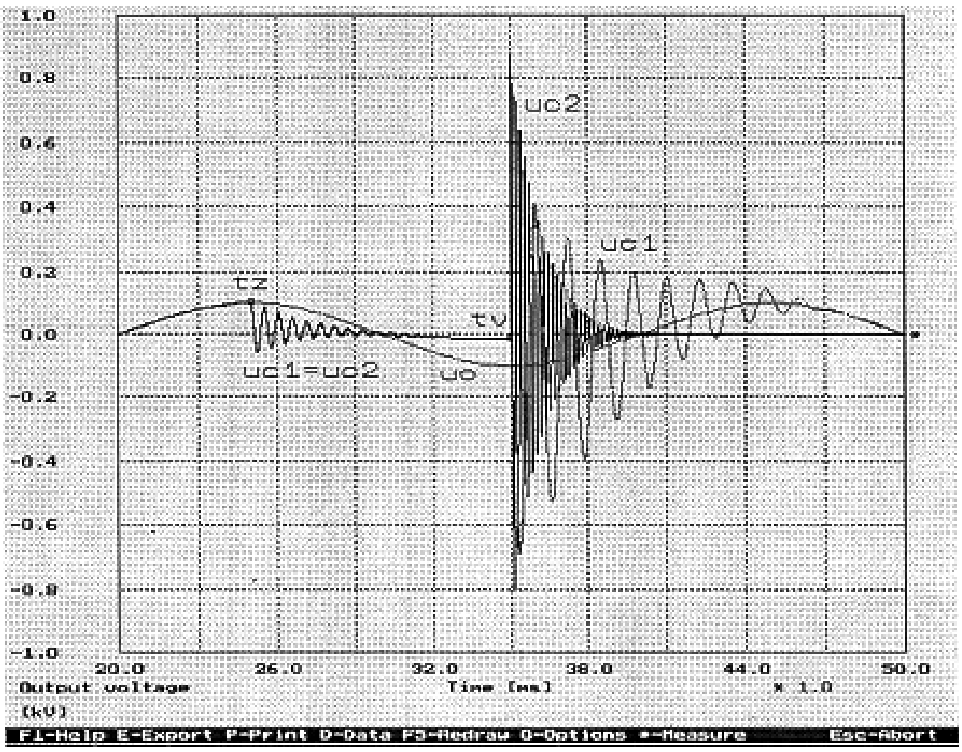


Figure 4c: Voltage response.

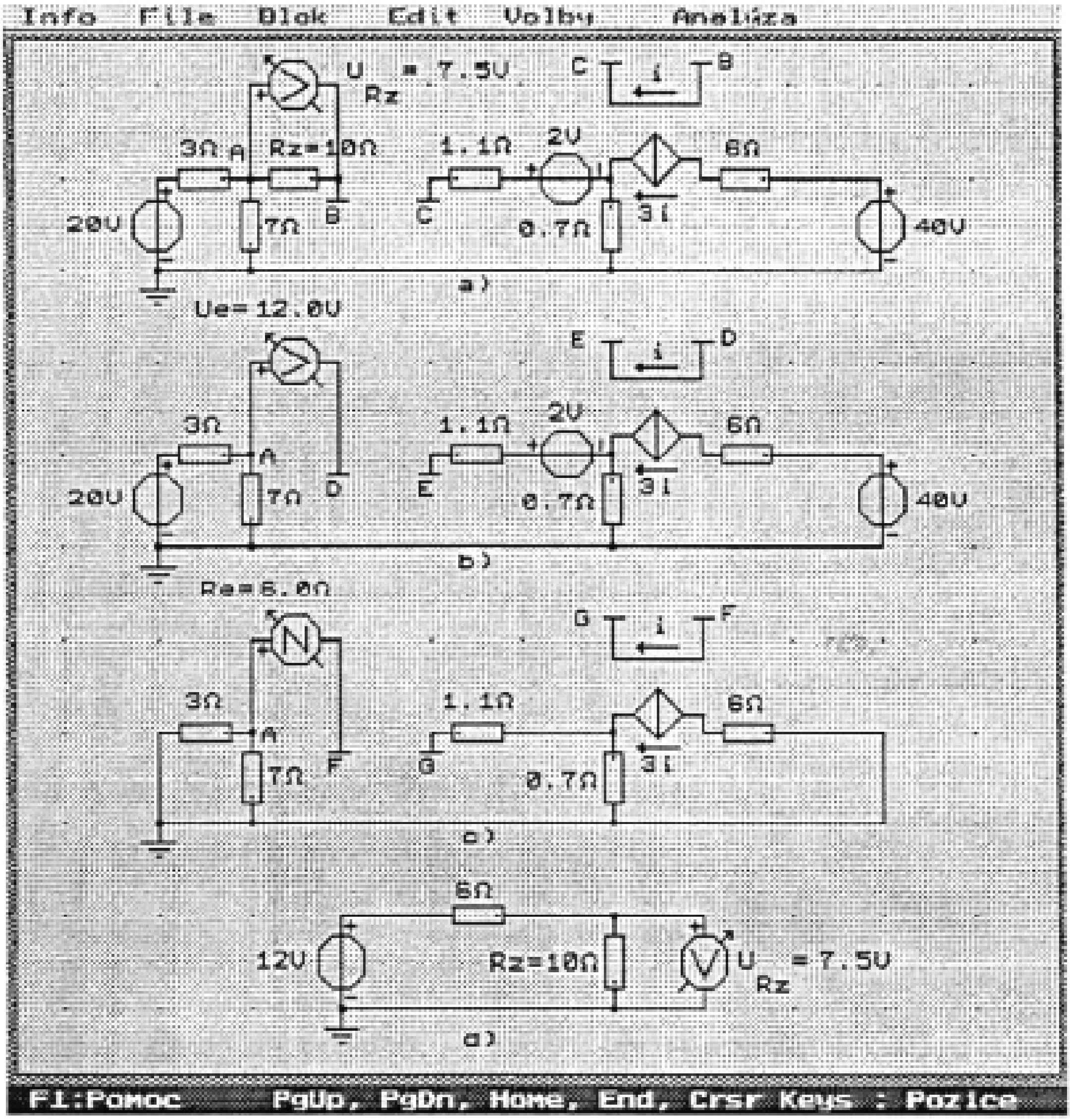


Figure 5: A circuit with a current-dependent current source in which we are a) looking for the voltage across the load resistance R_l; b) *measuring* the equivalent source of voltage; and c) *measuring* the equivalent resistance. d) Thevenin's equivalent circuit.

AC and DC operation. In Figure 6 a virtual oscilloscope is shown whose behaviour and control is analogical to a real oscilloscope.

Examining and consulting programmes in ECT

- For undergraduate students practical teaching programmes are suitable. Users can make their own electric circuit from simulated *real* elements and can also easily explore its qualities up to a simulated breakdown. Then they can *repair* the damaged element and can continue experimenting. These simulated experiments can be completed with check questions. For greater vividness these programmes are available in *three-dimensions* (Figure 7).

CONCLUSION

Contemporary computer science and pedagogical tutorial software open new possibilities in teaching technical subjects. Their introduction has been hindered by established pedagogical methods and also by the conservative thinking of some teachers.

The problems of using pedagogical software in the field of ECT are dealt with in this paper. It is suggested that a student can comprehend the behaviour of electric circuits in less time and not only in a formal way, but also by understanding electromagnetic processes that occur in electric circuits. Illustration can also be supported through animations. A student is freed from using difficult, demanding and unattractive mathematical apparatus, especially

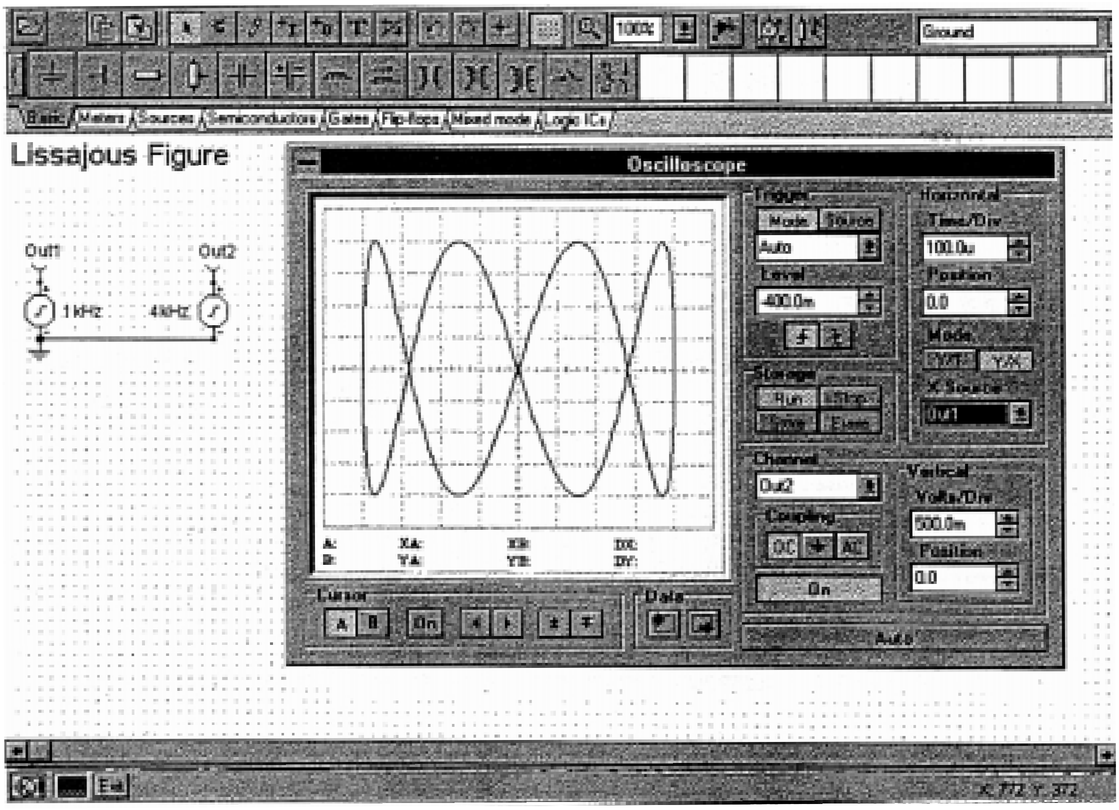


Figure 6: A virtual oscilloscope of the TINA programme.

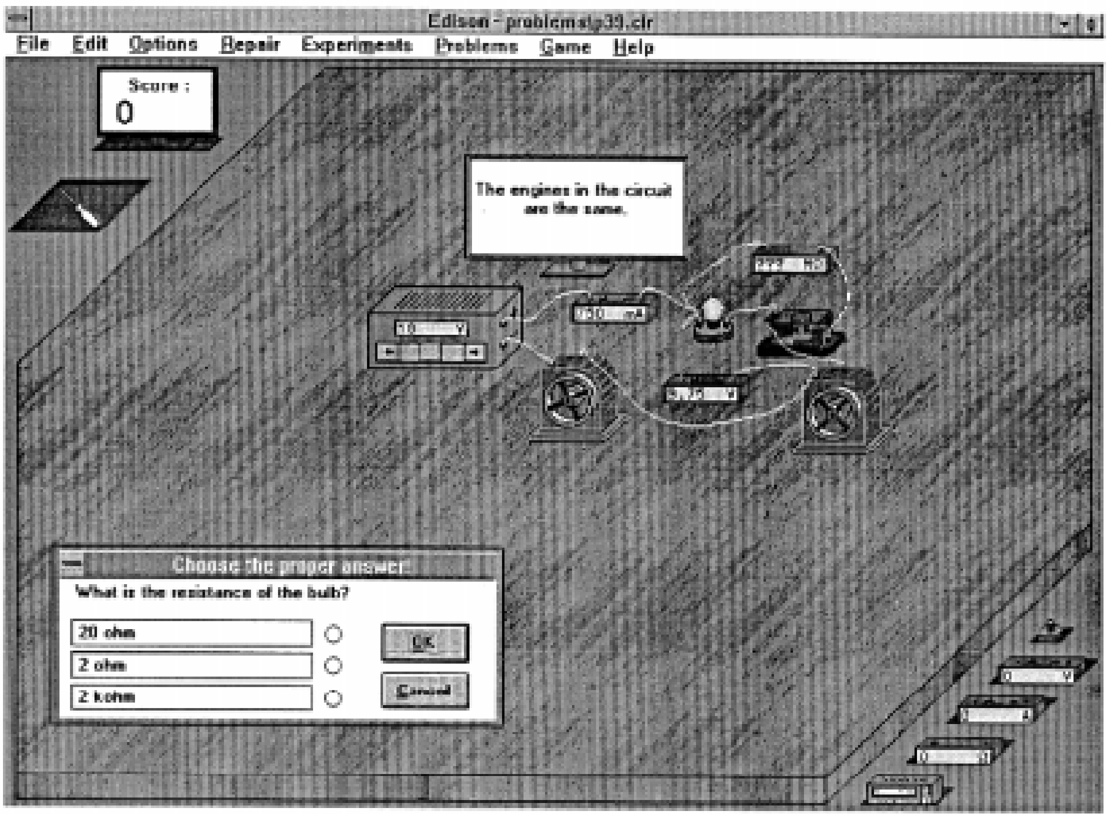


Figure 7: Making a circuit with the help of the EDISON consulting and testing programme.

in the solution of algebraic and differential equations and their systems.

Besides the analysis and synthesis of the circuits, the conception of computer-aided teaching offers a wide range of other pedagogical possibilities, of which simulated digital measurement in electric circuits with the help of virtual measuring apparatus, or use of testing and consulting programmes should be mentioned.

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BIOGRAPHIES

Daniel Mayer was born in Pilsen (Czech Republic) on August 8, 1930. He received the degrees of Ing, PhD and DSc in electrical engineering from the Technical University of Prague (Czech Republic) in 1952, 1958 and 1979 respectively. In 1956 he began his professional career as a Senior Lecturer and later as an Associate Professor at the University of West Bohemia of Pilsen. In 1968 he was appointed Full Professor of the Theory of Electrical Engineering. He was Head of the Institution of Theory of Electrical Engineering at W-B University in Pilsen for many years. His main teaching and research interests include circuit theory, electromagnetic field theory, electrical machines and apparatus, methodology of electrical engineering education and the history of electrical engineering. He has published five books and over 160 scientific papers in these fields of study.

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Josef Kus was born in Dobrany (Czech Republic) on August 10, 1936. He studied electrical engineering at the Technical University in Pilsen and received the degrees of Ing and PhD in 1958 and 1990 respectively. He is employed as a Senior Lecturer in the Faculty of Electrical Engineering of the University of West Bohemia in Pilsen. He teaches in a broad range of disciplines, but his main interests lie in the area of electrical circuit analysis and synthesis and electrical engineering education.

Proceedings of the 3rd East-West Congress on Engineering Education

under the theme:
Re-*Vitalising Academia/Industry Links*

edited by Zenon J. Pudlowski

The *3rd East-West Congress on Engineering Education* was held at the Gdynia Maritime Academy, Gdynia, Poland, between 15 and 20 September 1996, under the theme *Re-Vitalising Academia/Industry Links*. It brought together more than 170 delegates from academic institutions from 33 countries, east and west, under the general theme of *Re-Vitalising Academia/Industry Links*. The Congress papers are assembled, in order of presentation, in this comprehensive volume.

Two principal issues at the centre of the global dialogue between engineering educators are furthered in the papers collected in this volume. The first concerns common problems within the discipline in an age of rapidly changing technology. The second issue involves the restructuring of university engineering education in Central and Eastern Europe, in the context of the new economic conditions prevailing in the former socialist block. This latter can properly be considered to be an underlying theme, objective in fact, of the Congress.

Australia's participation, second only to that of the host nation itself, is evidence of the UICEE's and AAEE's success in fostering the international involvement of engineering educators in Central and Eastern Europe.

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