New Web-Based Interactive E-Learning in Power Electronics and Electrical Machines

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Abstract. This paper introduces a new software tool for teaching power electronics and electrical machines. The tool consists of HTML text where small programs in form of Java-applets are inserted which are used for interactive animation, simulation and design of power electronic circuits and/or electrical machines. The whole tool does need just a standard web-browser, is fully independent of the underlying operating system, also no installation is necessary, and all interactive Java-programs are written with the focus on very easy usage. Therefore, the tool can be accessed via the World Wide Web and/or by a CD-ROM in stand-alone PCs by students and professionals. Since the Java-programs are simple to handle, a student can immediately start working with the programs and can fully concentrate on the theory of the problem instead of studying help-manuals.
Because of the underlying software technology the tool can be used for on-line learning and can be easily integrated into an E-Learning platform for distance learning. It can be also used in the traditional classroom with laptop and beamer, via Internet or CD-ROM. Therefore, it can be integrated in a course making use of other modern technologies like video, slide-shows or sound-clips. It can be used by professionals or students for self-studying.
The focus of this paper is on the introduction of the usage and the technology of this new E-Learning software tool which is optimized for education in power electronics and electrical machines. It is not about certain teaching techniques. The E-Learning tool as presented at the conference can be found at **www.pes.ee.ethz.ch**.

1 Introduction

1.1 Motivation for Introducing E-Learning

There is a lot of discussions about declining numbers of students in power engineering at the universities. New ways of teaching might help to make these subjects more attractive to students. One approach is the introduction of the so-called "E-Learning".

More generally, using new media and IT-technologies in classroom can not only make studying more attractive to the student, but might make also teaching much easier. Especially in engineering classes complex technical problems have to be presented in a way which is easy to follow and understand. If, additionally, the problem shows dynamic behavior and/or a lot of different possible states do occur teaching becomes very hard for the instructor using only words and static pictures. Here, interactive animation (as shown in the following) might help a lot.

Another big advantage of E-Learning is the independence of working place and time. The student has the opportunity to learn in his favorite environment at the time of his choice.

This might not be seen as a great advantage for the university student, but it is especially important for the working engineer who wants to update his knowledge by taking E-Learning lessons in the evening after work and on the weekends at home.

There are a lot of publications in this field and the phrase "E-Learning" is used for a lot of different approaches.

1.2 E-Learning: A Lot of Different Approaches

Many papers focus on distance-learning via the Internet, where typically multi-media rich web pages are offered to the student sitting at home in front of his computer, taking lessons in a certain subject, while he keeps contact to other students and the teacher via e-mail, chat-rooms, on-line tests and similar things. This approach gives the advantage of full working place-independence for the student. If there are not pressing deadlines for homework and tests, there is also the advantage of a certain amount of working time-independence for the student. Today, there are different web-based platforms available that offer tools like chat-rooms, presentations, web-page generation and so on in one package. The user (the professor) doesn't have to write code (like Java, JavaScript, HTML or XML) but he has to configure the platform according to his certain subject and add content.

Other papers focus on the style of teaching under the impression of extensive usage of multi-media like video-clips, audio or „slide shows" in the classroom or via distance (Internet), where especially the efficiency of these new methods in teaching is discussed. As a platform to deliver a huge amount of multi-media based material the Internet is proposed, although the often limited bandwidth is a problem. In such an approach the content of the lesson is extended by visual and audio-format material.

There are only few papers dealing with the combination of text explaining the theory with interactive programs that allow the student to do little experiments via a simulator or solving some engineering problems. A main problem with this approach is the seamless integration of text and interactive programs which is necessary to give the student a tool to start working immediately without wasting his time with sometimes frustrating installation of a large number of plug-ins, or of a few complex executable programs that might be unstable or not working on his system.
One technology of such a successful integration is realized in this new E-Learning software tool and discussed in the following. Due to the employed technology the usage in education is extremely flexible. It can be used for distance-learning via the Internet, in more traditional lessons in the classroom (with or without the use of other multi-media tools), or for self-studying at home.

2 Technology of the E-Learning Software

2.1 Requirements

Generally, to make such an E-Learning software tool as convenient and flexible as possible the following points have to be taken into consideration:

- Independence from the operating system of the computer
- Usage of a widely accepted text-standard
- Possibility to make the tool web-based
- Programs written in an efficient language being able to solve numerical calculations within an acceptable time
- Using software standards that are widely accepted, backed by industry and long-term concepts also supported in the future

All these requirements are perfectly fulfilled by Java and HTML. The text explaining the theory is written in simple HTML, while figures (for example schematics of power circuits or other graphics) are inserted using the well-known space-optimized GIF- and JPG-formats.

2.2 Interactive Animation und Simulation

The Java programming language makes it very easy to insert programs into the HTML text in form of so-called „Java-applets" which feature full-functional interactive animation-, simulation- or design-programs. Java is supported by Netscape Navigator, Microsoft Internet Explorer, Opera and others. Because these web-browsers are available for many different operating systems, the Java-applets are largely platform-independent.

Java makes it a simple task to develop interactive graphical user interfaces which are easy to use. This is a very important feature, because the student does not have to read manuals to be able to start working but can start immediately studying the engineering problem. A graphical user interface also helps to avoid a large number of buttons and submenus for setting parameters of the engineering problem because this might be confusing for the user.

Today Java 1.1 is supported by all major browsers. To use new features in Java 1.2 and 1.3 like Swing (strong support of GUI programming) a Java 2-plug-in is necessary. Since a lot of people hesitate to install plug-ins, we decided to write all Java-applets in Java 1.1. Therefore, for our E-Learning tool no plug-ins are necessary at all.

One special feature of the new E-Learning software tool is numerical simulation of the time-behavior of certain voltages and currents of various power converter circuits. Although numerical computation is very time-intensive the speed of the simulation using programs written in Java is still very high (also in comparison to commercial simulation software).

Furthermore, the code of the simulation program is very compact. The simulation program of a single-phase boost converter is, e.g., just does occupy just 37kB. This is necessary to keep the download-times low also for people with slow modem connections since E-Learning is dedicated to people working and studying at home. Generally, we tried to keep the size of the applets of one HTML page in any case lower than about 70kB. This is comparable to downloading one or two photos from the Internet.

2.3 Presentation of Text in HTML

To create an interactive E-Learning tool it is necessary to employ little programs as explained before. Presenting additional explaining text might help the student a lot. The text is closely placed to the relevant applet and explains in simple words what the applet does present, how it can be used and manipulated and what can be shown and seen. The student is encouraged by the text to change certain parameters of the applets (like reference output voltage of a boost converter) and to study the effects (for example, resulting change of the modulation index). The student is asked certain questions and answers are given. Therefore the tool is comparable to a textbook with interactive pictures.

Most computers connected to the Internet today have browsers understanding HTML. So the use of HTML is quite natural in order to make the E-Learning tool available to as many people as possible.

Another big advantage of HTML is the ease of adding translations into languages other than English or German, for example. At the moment, the E-Learning software tool is available in German and English. A Japanese version is planned. This language has got its own characters, however, these can be quite simply realized using HTML.

2.4 Employing XML

XML is a very new data-format which is intended to make data platform-independent. There exist a lot of different applications of this format today. Basically, it is a very simple data-format where data is structured by so-called "tags" which comment on the data in a standardized way. We used XML to define the configuration data of the animated circuits (for example, describing the coordinates of the current paths for certain switching states for a lot of different power electronics circuits). The big advantage provided by XML is that the data is structured by comments. No extra documentation is needed during development. This is especially helpful and timesaving when there is more than one programmer working on the development of applets.

2.5 Summary

In order to make the E-Learning software tool available for a large number of people it has to based on a technology which is generally independent from the operating system of the computer, which can be used easily without complicated installing of software and plug-ins, which is stable and supported by industry and/or will still be here in the future, and which can be made available via the Internet. HTML-text and embedded Java-applets are a perfect choice for all requirements. To keep development-time and costs low we employ XML for storing all data used by the Java-applets.

3 Teaching Power Electronics

A few representative Java-applets for interactive animation, i.e. controller design and numerical simulation of the time-behavior of selected signals are presented in the following section. The applets are inserted seamlessly into the explaining HTML text and offer a very simple and self-explaining graphical user interface. The whole E-Learning software tool consists of many more Java-applets like the

following examples forming together with the HTML text a full one-semester basic course on power electronics discussing

- Basic topologies of DC/DC converters
- Single-phase PFC rectifiers
- Control theory of PWM rectifiers
- Inverter circuits (H-bridge)
- Diode rectifiers (single- and three-phase)
- SCR rectifiers (single- and three-phase)
- DC-motor drives
- Theory of phasors and space-vectors

The E-Learning tool is available at the web-page of the Power Electronic Systems Laboratory, ETH Zurich, Switzerland, at http://www.pes.ee.ethz.ch.

3.1 Interactive Animation

3.1.1 General Aspects of Interactive Learning

Learning or teaching of a technical subject is often difficult because there is a large number of possible reactions of a system to parameter changes. The underlying dynamics are generally time-dependent. Conventional presentation of such challenging content is to provide a sequence of pictures showing time- and/or parameter-dependent snapshots of the system behavior in case of a parameter change. The pictures are presented on paper (textbook) or by using a beamer (classroom).

If the same content is presented in the form of a short movie, the dynamic system behavior can be explained much easier in many cases. Techniques like slow-motion and repeating sequences, or highlighting important areas of the system are used to focus the attention of the student on the important points. One problem with this approach is the subjectively different time people need to understand a technical problem. In classroom students are limited in influencing the speed of the animation (movie). Another negative effect is that students understand what they see but are not able to remember and apply that knowledge since it is a big difference in passively watching someone doing something and actively doing this certain thing by oneself.

In the new E-Learning software tool the Java-applets are capable of acting like movies demonstrating complex and/or dynamic system behavior. Additionally they offer the possibility of actively manipulating system parameters with the mouse via graphical user interface and study the resulting time- and frequency behavior of the system. The HTML text gives hints how to "play" with the system in order to understand why certain system reactions occur. This way of learning is prior to the classical approaches described above since the student is actively involved.
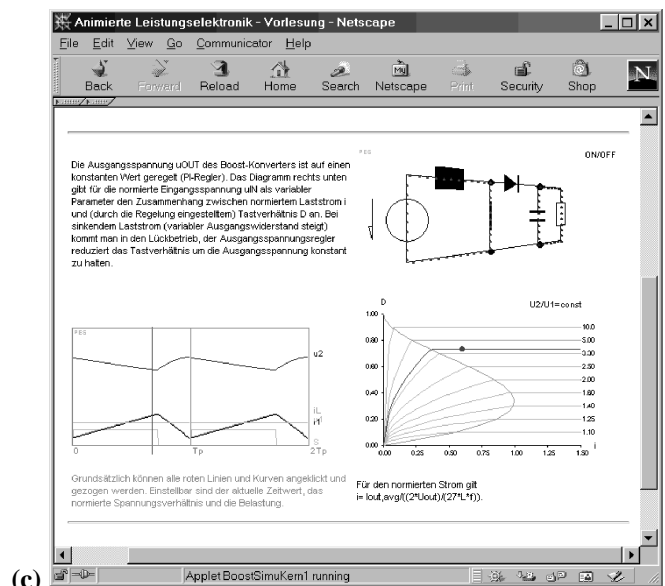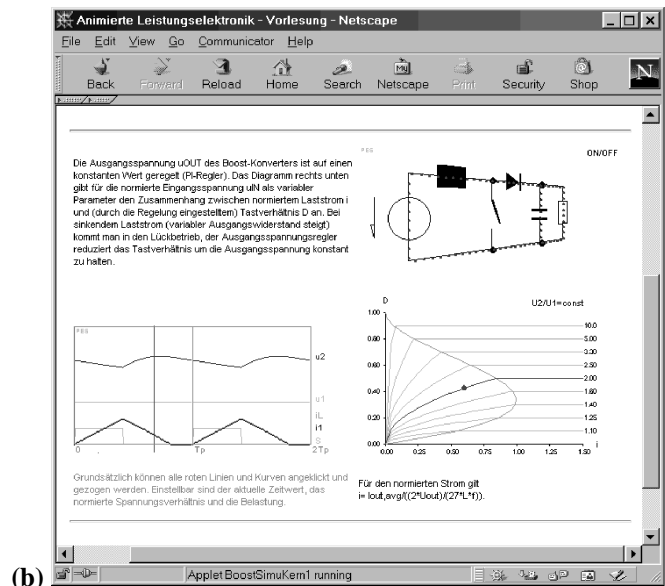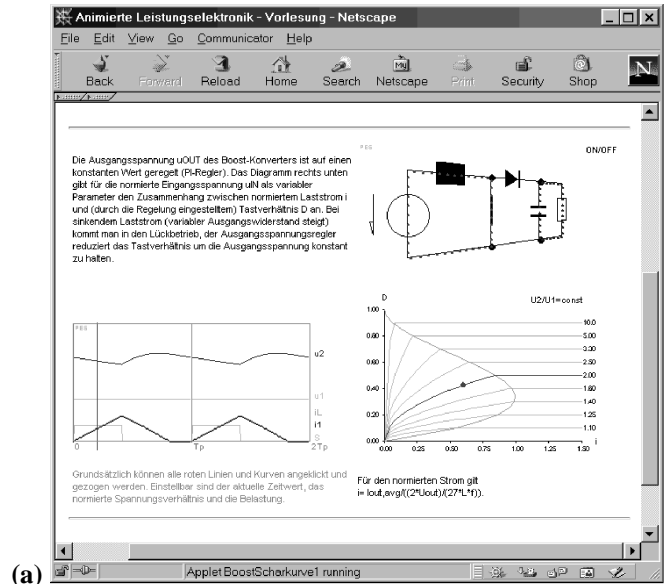

Fig.1: **(a)** First vertical line in bottom-left applet marks time at switching state S=ON. **(b)** Time-marking vertical line marks S=OFF, switch in top-right applet is in off-state now. **(c)** The normalized load

of a boost converter. The desired ratio of output and input voltage is changed in the diagram (bottom-right applet) and the time-behavior is adjusted accordingly (bottom-left applet).

In the following a few examples of Java-applets for interactive learning and interactive animation are given in detail. Since the applets are designed not to be constrained by non-interactive static paper, the following description is quite limited and somehow poor. However, all examples can be found and tested under www.pes.ee.ethz.ch.

3.1.2 Example Boost-Converter

To understand the operation of the boost converter it is necessary to know the current path in dependence of the state of the power switch. In the applet of the power circuit (top-right in **Fig.1**) the actual current path is marked by moving colored points ("positive charges") and the visual representation of the power switch is different for on- and off-state. The second applet (bottom-left in **Fig.1**) shows the time-behavior of currents and voltages for two switching periods just as one would see it on an oscilloscope in the laboratory. A main feature here is a vertical (red) line marking the actual time which can be dragged by the mouse. This actual time defines the current path animated in the power circuit applet. The third applet (bottom-right) shows the diagram of the duty cycle required for keeping a desired ratio of input voltage and output voltage in dependency of the (normalized) load. Voltage transfer ratio (the characteristic curve in the diagram) and normalized load (red point on the voltage-ratio curve) can be dragged. The new conditions are sent to the time-behavior-applet (bottom-left) which is updated according to the new conditions immediately. If the current-path state (defined by the vertical time-marker line) changes, this information is sent to the power-circuit applet. **Fig.1(a)** and **Fig.1(b)** show the effect of changing the time-marker line on the animated current-paths. **Fig.1(c)** shows the effect of changing voltage-ratio and normalized load.

3.1.3 Example B2-Diode-Bridge for Battery-Charging

The B2-diode-bridge of **Fig.2(a)** again shows a power circuit applet (top-right) with animation of the actual current path by moving colored points coupled with the mouse-draggable time-marker line of the time-behavior applet (bottom-left). This scheme was proven to be very effective and therefore is a key component in the E-Learning software tool. In addition to the vertical time-marker line there is in the same applet a horizontal line defining the battery-voltage level which can be dragged by the mouse. This is a simple but effective way for the student to experience the effects of battery voltage changes. There are also two gray voltage-time areas shown in this applet which give the voltage-time area applied to the inductor which is determining the inductor current shape. For stationary operation these two areas have always to be of equal size. There is also a diagram (bottom-right applet) giving characteristic parameters like normalized duration of the current flow in dependence of the normalized load current. Here, the operating points move according to the conditions defined by the battery voltage in the bottom-left applet. **Fig.2(b)** shows the effects if the battery voltage is reduced to relatively low values.
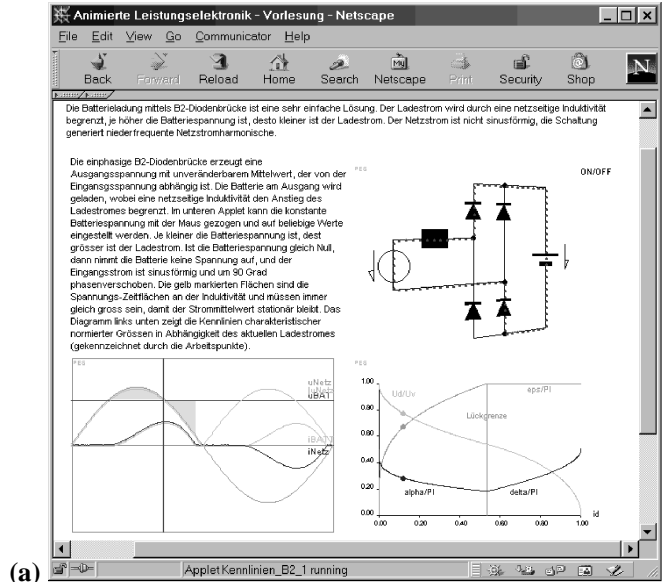
(a)
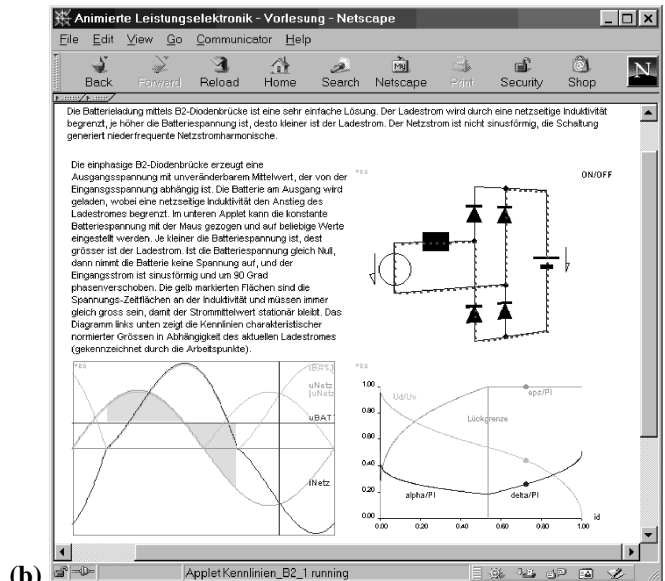
(b)

Fig.2: (a) First vertical line in bottom-left applet marks time during iL>0 defining the animated current paths in top-left applet of the power circuit. Gray voltage-time areas (in bottom-right applet) determining the inductor current shape iL are indicated. **(b)** Horizontal line in bottom-left applet defining the battery-voltage can be manipulated by mouse-dragging; this resulting in an increase or decrease of the current drawn from the mains.

3.1.4 Example Single-Phase PFC

In the section on the single-phase PFC rectifier (**Fig.3(a)**) the mouse-draggable time-marker line of the mains-period time-behavior applet (bottom-left) defines a small time-section shown in a zoom-applet (bottom-right). Here one can study the details of voltages, currents and switching signals of a certain time within the mains period. The zoom-applet (bottom-right) also shows a mouse-draggable time-marker line which is coupled with the animated currents of the power circuit applet (top-left) as described before. **Fig.3(b)** shows a different position of the zoom-applet within the mains period.

An additional feature of these applets is the possibility to switch the PFC-simulation with one mouse-click into a B2-

diode-bridge. This is easily done by fixing the power switch in a continuous off-state. This is shown in **Fig.3(c)**, where significant low-order harmonics of the rectifier input current do occur. The other functionalities are as described for **Fig.3(a)** and **Fig.3(b)**.

Another feature is the possibility to switch the zoom-applet into a diagram which shows the harmonics of the input current of the rectifier by a single mouse-click (**Fig.3(d)** for the B2-diode-bridge). This feature powerfully demonstrates the advantages of PWM rectification concerning given restricted for emission of low-order current harmonics.
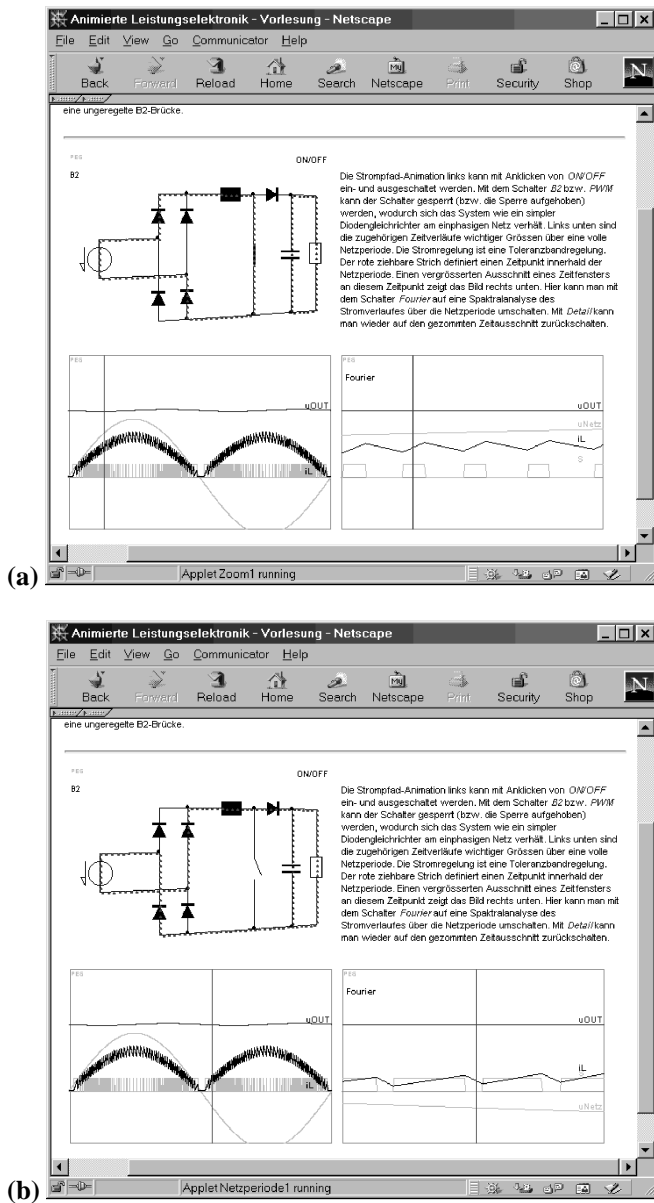

(a)

(b)

Fig.3: **(a)** Bottom-left applet shows time-behavior of currents and voltages of the PFC within one mains period, vertical time-marker line defines time-position of zoom-window (bottom-right applet), vertical time-marker of zoom-window defines animated current paths in top-left applet of the power circuit. **(b)** Time-marker line of bottom-left applet defines new zoom window (bottom-right applet). The current paths of the top-left applet are changed accordingly.
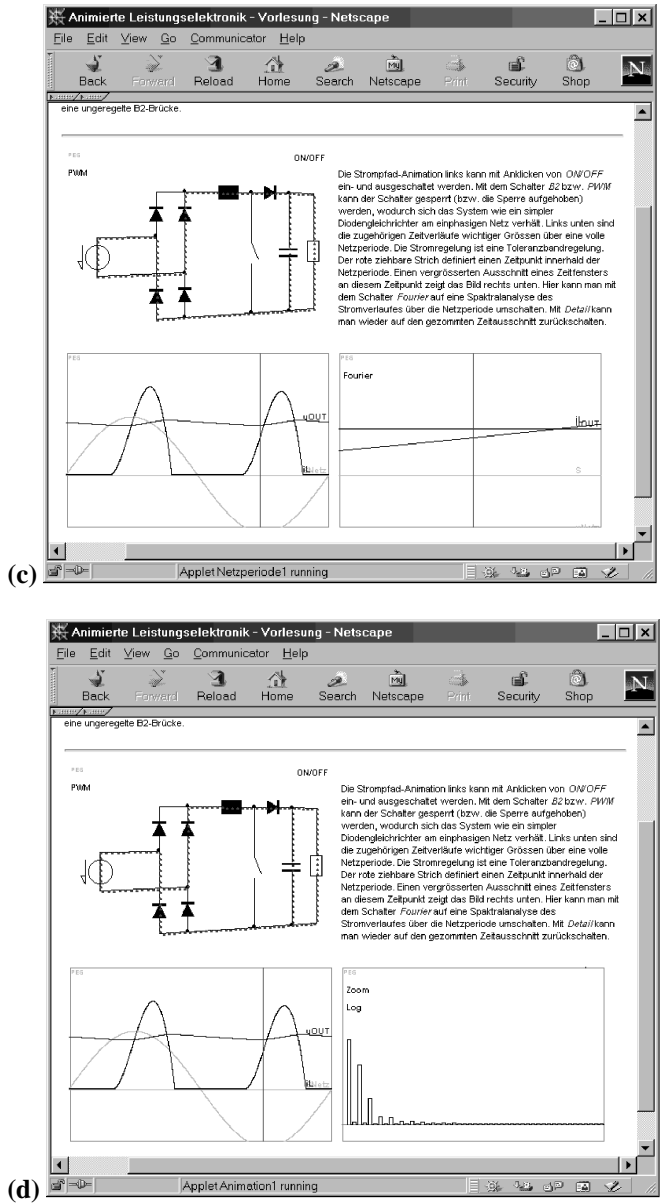

(c)

(d)

Fig.3 (continued) **(c)** The PFC can be switched into B2-diode-bridge by fixing the switch in the off-state. **(d)** Zoom window (bottom-right applet) can be switched from zoomed time-behavior into a diagram showing the Fourier-spectrum of the rectifier input current (as shown in the bottom-left applet).

3.1.5 Example H-Bridge

The H-bridge is a basic concept in modern power electronics.. Although the concept of intersecting a high-frequency triangular carrier signal with a (sinusoidal) reference signal to define the switching points is not very difficult to understand, there are a lot of possibilities for the values of all the signals, voltages and currents, which makes it sometimes hard for the student to understand all the details. Explaining the concept of the H-bridge with conventional teaching techniques requires a lot of pictures with a confusing diversity of parameters. .

The applets of **Fig.4** are sufficient to demonstrate all basic operating states of the H-bridge. The top applet shows the time-behavior of all necessary control signals, which is the triangular carrier signal and the sinusoidal reference signal. There are three red points in the top applet that can be mouse-

dragged to change the frequency of the carrier signal, and to change amplitude and phase of the sinusoidal reference signal. The states of frequency, amplitude and phase are sent to all other applets resulting in immediate updating of all graphs.

The second applet shows the time-behavior of the PWM voltage at the inverter output, its fundamental, the fixed sinusoidal voltage of the AC-voltage source at the output side, and the resulting output current. In this applet there is also the already introduced vertical mouse-draggable time-marker line which defines the animated current path in the power circuit applet (bottom-left). The use of the time-marker only makes sense if the switching frequency (defined by the carrier signal in the top applet) is not too high. The third applet gives the time-behavior of the actual input- and output-power.

There is also a phasor-diagram applet (bottom-right) which shows the actual values of the complex time-phasors of the AC source voltage, the fundamental of the PWM voltage, the resulting fundamental voltage drop across the inductor and the fundamental of the resulting output current. In this applet there is a red point to be dragged by the mouse for changing the amplitude and the phase of the sinusoidal reference signal (top applet) alternatively. This gives an effective coupling between analysis in time-behavior and time-phasor diagram.
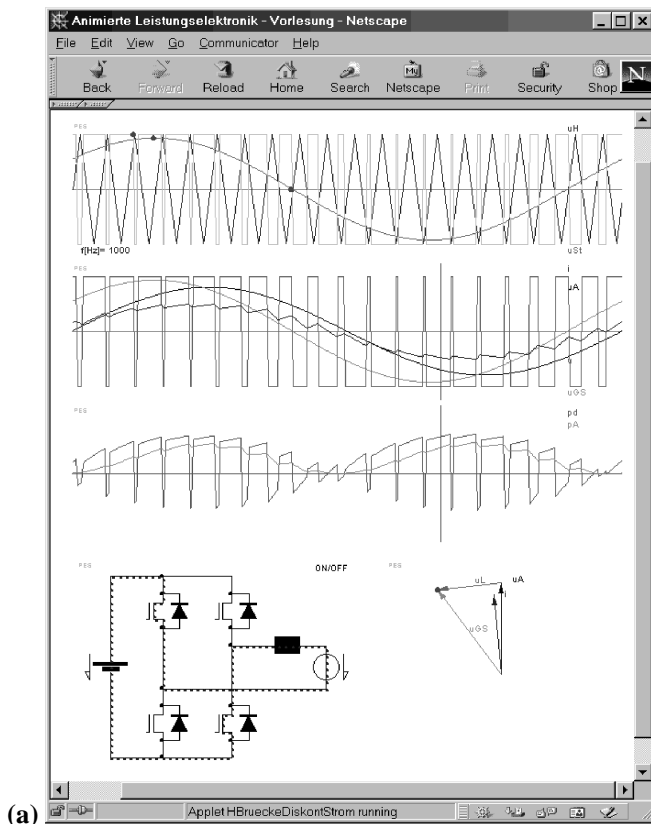

(a)

Fig.4: **(a)** Top applet shows triangular carrier signal and sinusoidal reference signal (amplitude and phase of the sinewave and frequency of carrier can be manipulated by mouse-dragging). Second applet shows resulting PWM voltage at the inverter output side, the fundamental of this PWM voltage, and the output current with ripple. Dragging the vertical time-marker line defines the state of the animated current path in the bottom-left applet of the power circuit. The third applet gives the time-behavior of the input- and of the output power of the H-bridge. The bottom-right applet shows the according time-vector diagram where mouse-dragging changes all time-behaviors in the other applets.
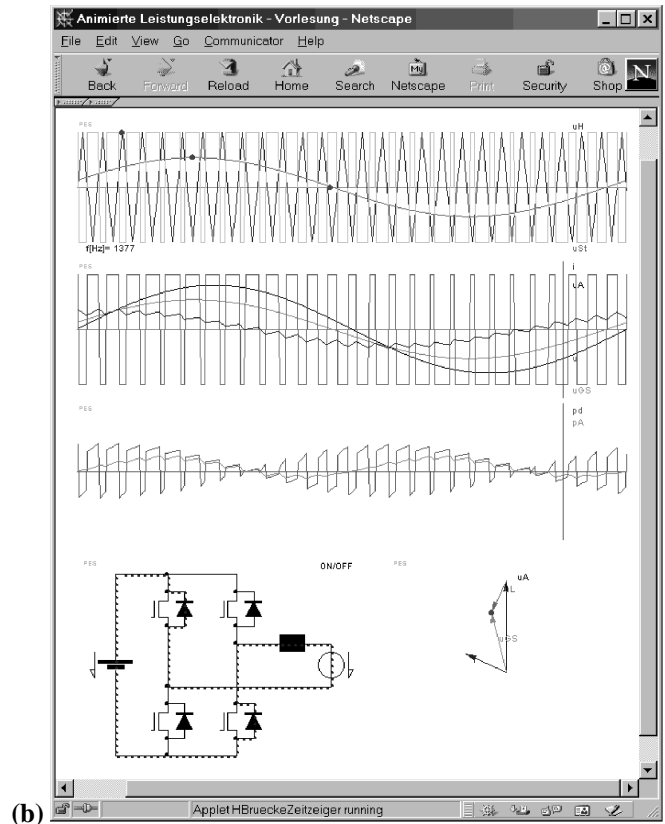

(b)

Fig.4: **(b)** Changing of the sinusoidal reference in the top applet in amplitude or phase influences all other applets accordingly. The same effect can be reached by mouse-dragging the phasors in the bottom-right applet showing the time-phasors. Also, in this picture, the carrier signal frequency is higher than in Fig.4(a).

3.2 Controller Design

3.2.1 General Difficulties Studying Controller Design

Another important feature of the proposed E-Learning tool is the possibility to study, understand and also perform controller-design using Bode-diagrams or root square locus schemes. For proper design of the controller of a power converter there are various theories which support the design process. Since many of those are mathematically complicated they often seem unattractive and therefore are neglected by many students. This E-Learning software tool supplies Java-applets for certain power circuits which explain step by step the controller design process, i.e. block diagrams, linearization, small-signal equivalent circuits and corresponding transfer functions, and finally the Bode and root locus diagram. Because the complicated mathematical issues (like computing all complex roots of high-order polynomials) is hidden in the Java-applet the student can concentrate on the more engineering part of the problem like defining the equivalent circuit, setting circuit parameters and interpreting the results of the diagrams. An example is given in **Fig.5** for a boost-converter.

3.2.2 Example Controller of a Boost Converter

Fig.5 shows the linearized equivalent circuit of the single phase PWM boost rectifier with emphasis on the design of the inner input-current control loop and the outer output-voltage control loop. Each loop results in a different root locus diagram, where all circuit parameters can be set. The value of the defined circuit parameter can be manipulated by the slider, the actual value is given in the box below and marked inside the root locus diagram. The functions of controller and of the transfer function in the Bode-diagram change according to the position of the slider.
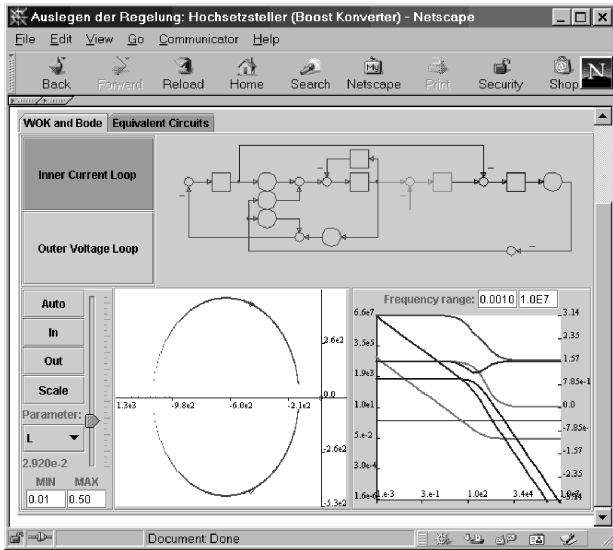

Fig.5: At the top the linearized block diagram of the boost-converter is shown. Bottom-left diagram shows the root-locus plane with the possibility of changing one arbitrary circuit parameter. Bottom-right diagram shows the according Bode-diagram for transfer function amplitude and phase. (This applet is a prototype employing Java Swing and will be redesigned and rewritten in Java 1.1.)


(a)
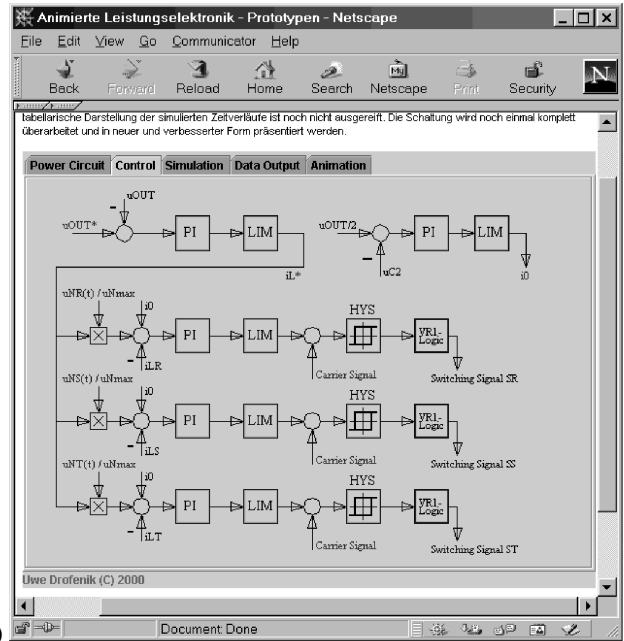
(b)
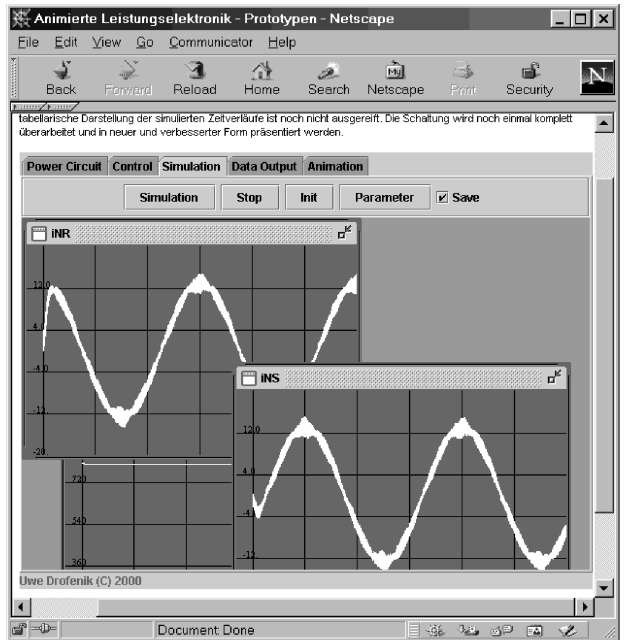
(c)

Fig.6: **(a)** Power circuit of the three-phase boost-type VIENNA Rectifier 1. All component parameters can be mouse-clicked and changed via pop-up window. **(b)** Control circuit of the VIENNA Rectifier 1. Also here, all control parameters can be mouse-clicked and manipulated. **(c)** Numerical simulation results for the input currents of two phases. (This applet is a prototype employing Java Swing and will be redesigned and rewritten in Java 1.1.)
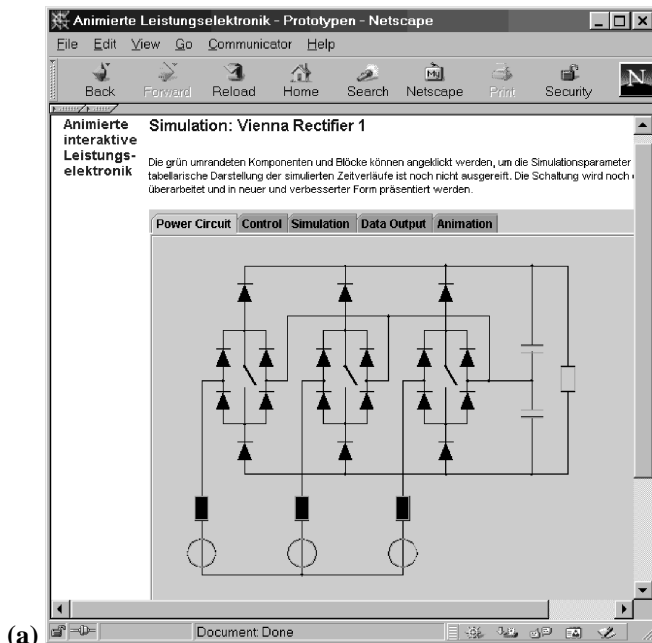
3.3 Simulation

3.3.1 Simulation in Education

The GUI of the Java-applets for simulation of the time-behavior of certain power circuits will be familiar to people working with simulation programs. Since with the E-Learning software tool the Java-applets are inserted at the appropriate text, the various simulation programs are dedicated to the actual power circuit being discussed. Therefore, the

simulation programs within the E-Learning tool have fixed power and control circuit topologies where only the parameters can be changed via the graphical user interface. There is no possibility to change the power circuit by drag-and-drop of components as it is known with simulation programs like PSpice, Simplorer or Caspoc.

This is no drawback since the students use the E-Learning tool to study basic behavior of standard systems. The students might change circuit and control parameters to experience how the system operating behavior is influenced, but do not explore new topologies in this basic course on power electronics.

As an advantage of the fixed topologies, the algorithm for the numerical simulation can be optimized concerning downloading time and simulation time. The numerical simulation of such a Java-applet in a web-browser is often faster than compiled simulation programs which are optimized for power electronics. Additionally, the size of the applets size can be kept very small.

3.3.2 Example VIENNA Rectifier 1

Figure 6 shows the applet for the simulation of the VIENNA Rectifier 1, a three-phase three-level unidirectional PWM boost-PFC. The parameters of the components of the power circuit and the controller parameters can be manipulated by mouse-clicking of the according component (**Fig.6(a), (b)**) via a pop-up window. The simulation of the time-behavior of the input currents is shown in **Fig.6(c)**. The simulation can be stopped, the parameters can be changed as desired, and the simulation can be continued. The size of the time-step for the numerical simulation is set by the user via the "Parameter"-button. The resulting simulation data can be exported via "paste and copy" into other applications and programs for postprocessing. For security reasons it is very difficult to write data processed by an applet directly onto the hard-disk.

4 Summary

A new platform-independent E-Learning tool for education in power electronics and electrical machines has been introduced. The E-Learning tool can be used via the Internet or via CD-ROM due to the combination of HTML and Java-applets. The Java-applets inserted into the HTML text are written for interactive animation, controller design and simulation with an easy-to-use self-explaining graphical user interface.

The E-Learning software tool realizes a complete basic course in modern power electronics running over one semester. Due to the underlying technology the tool is very flexible in use. It simplifies teaching when used with a laptop and beamer in the classroom. It simplifies studying the basics of power electronics for both the student and the engineer who wants to update knowledge at home after work. Interactive animation is very efficient for studying because the student is actively involved.

It is planned to finish this E-Learning tool in all details at the end of 2001. The course is available in German and English at www.pes.ee.ethz.ch. Furthermore, it is planned to create a comparable E-Learning software tool for an advanced course on power electronics until mid of 2002.

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