

Survey of Modern Approaches of Education in Power Electronics

Uwe DROFENIK and Johann W. KOLAR

Power Electronic Systems Laboratory
Swiss Federal Institute of Technology Zurich
ETH-Zentrum / ETL H12, CH-8092 Zurich, Switzerland
Phone: +41-1-632-4267, Fax: +41-1-632-1212
E-mail: drofenik@lem.ee.ethz.ch, kolar@lem.ee.ethz.ch

Abstract. This paper introduces a new software tool “iPES – Interactive Power Electronics Seminar” for teaching and self-studying power electronics. iPES consists of HTML text where Java-applets (small programs) are inserted which are used for interactive animation and simulation of power electronic circuits and electrical machines. The whole tool does need just a standard web-browser and is fully independent of the underlying operating system. No software installation is required, and all interactive Java programs are written with the focus on very easy usage. The tool is available at www.ipes.ethz.ch in English, German and Japanese, can be accessed via the World Wide Web or used with a CD-ROM in a stand-alone PC.

1 Introduction

In times of rapid changes of technologies it is essential for companies to provide employees with the possibility for updating knowledge on a regular basis. Efficient education in terms of time and costs is needed, therefore.

One approach to efficient education is the use of so-called “E-Learning”. There, the content of a course is presented by a CD-ROM or via the Internet, so that the students do enjoy independence of working place and time. The students furthermore do have the opportunity to learn in their favorite environment at the time of their choice. This might not be seen as a great advantage for the university students, but is especially important for the working engineer who wants to update his knowledge by taking E-Learning lessons in the evening after work or over the weekends at home.

Another aspect is education at universities and higher technical schools. Today, there is a lot of discussions about the declining number of students in power engineering at the universities. New ways of teaching might help to make such subjects more attractive to students.

However, using new media and information technologies in the lecture room can not only make studying more attractive to the student, but might make also teaching much easier and more effective. Especially in engineering classes complex technical problems have to be presented

in a way that is easy to follow and understand. If, additionally, the system to be described shows dynamic behavior and/or a lot of different possible states do occur teaching becomes difficult for the instructor in case only words and static pictures are at hand. Here, interactive animation (as shown in the following) might help a lot.

This paper tries to give an overview about approaches available besides iPES in education of power electronics which became realizable with the widespread use of information technologies. Slide shows now can be extended with audio text, sound and short movies what does make the slide also useful for self-studying at home. Numerical circuit simulation is a very important tool in addition to the student’s practical exercise in the laboratory, and there numerous programs especially for simulation of power electronic circuits are available today. There are projects to make presentations, text and simulations in the field of power electronics available via Internet in order to take advantage of the Internet’s time- and place-independency.

Advantages and disadvantages of the various approaches in education are discussed in the following and a comparison to interactive animation as realized in the iPES project is given.

2 Slide Show with Sound, Audio Text and Movies

2.1 Slide Show in Presentations – Advantages and Problems

Over the last years slide shows have become more and more attractive to the teachers. Today slide shows are a standard at every presentation, not only in companies but also in lecture rooms at universities. While a few years ago slides were often written by hand with students copying the teacher’s writing today almost all presentations are produced by office software, especially Power Point [5].

The teacher doesn’t have to write down what he would like to say but can concentrate on explaining things in more detail. The slides have to be produced once and can

be modified easily. Since it is nearly impossible to copy the slides that are often changed in quick sequence, the students should get all information shown on the slides in advance to the presentation in written form or on a CD ROM in order to be able to fully concentrate on the presentation.

However, there are also disadvantages of this kind of presentation. A student is in much more passive role now than ever before. He doesn't have to write down anything. It is dark in the room, and the student often feels that not following the presentation is no problem as he has got all the slides also for self-studying, although slides for presentations are often not designed for self-studying.

It is important that a teacher always does keep such risks of a presentation using slides in mind. It is still up to the teacher to motivate the audience and by a good slide show great results can be achieved.

2.2 Slide Shows for Self-Studying

The original idea of a slide show has been to support the teacher in the classroom by key contents like pictures, diagrams and equations which are difficult to draw on the blackboard. For self-studying at home due to the missing explanations of the teacher a textbook or written notes with more detailed explanations than given on the slide's content are necessary.

With new information technologies there are now different ways to extend slides with sound, audio text and short movies in order to make the material useful for self-studying. It is important to base the slide show on software which is commonly used on PCs in order facilitate the application.

Because of Microsoft's huge market share on the client-side Power Point is a quasi standard for slide shows. With Power Point animations are possible, furthermore audio and video clips can be embedded. The students can listen to the teacher's explanations which are synchronized with the visible contents on the screen. The students do experience the contents by watching and listening, and they could repeat sections which are difficult to understand. Besides Power Point the Acrobat Reader [6] is very popular and widespread tool, which does provide features comparable to Power Point so that slides can be extended with synchronized audio and video contents.

Furthermore, both programs do offer the possibility of running other programs like numerical circuit simulation from inside of the slide show. After studying the theory the student could immediately start a numerical simulation program to solve related examples [7].

Especially audio and video files are typically very large in size. Many students do not have latest computers at home and often the modem connection to the Internet does show a low data transfer rate. Therefore, offering such media-

rich educational presentations for download from the Internet is often difficult for the potential user, the student. Here, the best way of distribution today and also in the near future would be the CD ROM.

3 Numerical Simulation

Programs for numerical circuit simulation are a key component in research and development in the industry and in university laboratories today. In advance to building a prototype the main functions of a power electronic system are simulated on the computer what generally does save a considerable amount of time and money. In education simulation has become very popular, too. Simulation is less expensive and faster than building prototypes. For building prototypes often expensive components in small number have to be organized what is time-consuming and therefore often is disliked by students. Measuring equipment is also very expensive and often not available. In general more and more students at universities prefer to work with software rather than hardware.

A problem of focusing on numerical simulation is that a student would need some feeling for the hardware of the system he is simulating. Some hardware experience is necessary to make useful simulations. For example, students with no hardware experience will simulate systems which would not function in reality because parasitic effects like stray inductances, stray capacitances etc. are neglected in the simulation.

In education simulation is a perfect addition to some hardware experience gained in the laboratory. But, one has to be careful with eliminating all hardware experiments in education because this might result in a very abstract education of students who would not be able to build a real world system.

In power electronics SPICE [9] is a frequently used simulation program although it has been designed for the simulation of signal electronics. The SPICE algorithm is slow and often numerically unstable when simulating switched systems. SABER [10] is well known and widely used in power electronics since it is especially designed for switched systems. SIMPLORER [11] and CASPOC [12] are programs for numerical simulation in power electronics and are very easy to use, do show short simulation time and high numerical stability.

There are several other programs for numerical simulation in power electronics. For many of these programs textbooks with examples are available for students for the simulation of standard power electronic systems and the solution of related problems. This textbook-approach accompanied by examples is very powerful and popular and frequently used in university courses in addition to traditional lectures and practical exercises in the laboratory.

As a drawback one might see that programs for numerical simulation do consume a large space on the computer's hard disk and are designed to be installed on the computer. Furthermore, often a license is required in order to be allowed to run a simulation program.

4 Web-Based Simulation

The Internet does make education independent from a lecture room and a given lecture time. Furthermore, installation of a web-browser is standard on today's personal computers. If the content can be presented in the web-browser and programs like simulation and/or animation are able to run inside a web-browser there is no need for additional installations. With always shorter time periods between hardware- and operating-system updates forced by the IT industry installing software becomes more and more frustrating for the user. Running programs inside the web-browser avoids installations. This is especially useful for trying small programs for testing purpose. Another problem is the dependency of the software on the operating system. This problem is also eliminated if programs do run in a web-browser.

The technology which does it make possible to run programs in web-browsers is Java [13]. Java is a very popular programming language with a syntax like C, is object-orientated, and runs in a so-called virtual machine. Java has been written with emphasis on network programming and security, and is designed to run as a stand-alone application or, alternatively, inside a web-browser. If the web-browser can't handle Java, so called plug-ins are available to add Java-ability. The Java-programs running inside the web-browser are embedded in a HTML page and are called Java applets. Although Microsoft is creating its own standard for such tasks [14] at the time of this writing there are no alternatives to Java.

From the viewpoint of programming one has to consider that all these Java applets have to be downloaded from the Internet. The typical user is a student often using a slow modem-connection. Keeping this in mind the size of the simulation programs has to be kept as small as possible for keeping the downloading times short. Furthermore, the Java applet is running in the web-browser in an interpreted mode which means that it is not as fast as an executable program written in C++, for example. Simulations are time-consuming tasks and the Java programmer has to optimize the code in order to keep the simulation times short. Otherwise, long download times and slow execution do outbalance the advantages which the Internet is generally providing.

Another technical problem with simulation programs in form of Java applets is that Java restricts the ability to store simulation results on the local hard disk for security reasons. There is a mechanism for digitally signing Java applets and providing the applet with the right to write to the local hard disk if the creator of the applet is a trusted

institution. This mechanism is difficult to handle for a user without skilled computer knowledge. On the other hand this security restrictions are required because otherwise destructive Java programs might do a lot of harm, destroying the reputation of Java as a safe network language. One simple solution for Java applets is to provide the simulation results in form of columns and rows as text that can be copied and pasted into spreadsheet programs like GRAPHER [15] or EXCEL [16] for producing diagrams.

Providing Java applets for numerical simulation in power electronics does make use of several of the above listed advantages of the Internet. While one recently published university project is concentrating on basic power electronic circuits [17], [18] there are several other similar projects in other engineering disciplines but power electronics [19], [20], [21], [22], [23].

Such web-based projects are convenient from the user's point of view but from the viewpoint of education they are not different to the use of stand-alone simulation programs with textbooks and collections of examples.

5 Simulation in Combination with Text

While Java-applets for numerical simulation in power electronics mainly take advantage of the simple usage, easy distribution and compatibility of the Internet, there is a university project [24] which is based on embedding the Java-applets into HTML text. The result is an introductory textbook on power electronics where instead of circuit diagrams and figures Java applets are inserted where the student can set circuit parameters without explicitly starting a simulation and furthermore can immediately see the resulting time-behavior of various currents, voltages and signals. The text is very detailed and in addition to the Java applets there is also SPICE and MATLAB code for solving the examples.

6 Interactive Animation with iPES

At the ETH Zurich the "Interactive Power Electronics Seminar - iPES" has been developed. The idea was to put emphasis not on simulations but on interactive animation.

iPES, which available at no costs at www.ipes.ethz.ch, is a collection of Java applets which are used in addition to conventional teaching in the classroom in order to support the students with getting familiar with new concepts and basic circuits in power electronics. IPES is used in the introductory course on power electronics at the ETH Zurich and at the Nihon University in Japan.

In iPES basic power electronic circuits are visualized by an applet. The students can change various parameters with the mouse and watch the system's reaction immediately. Only the circuit parameters with the most

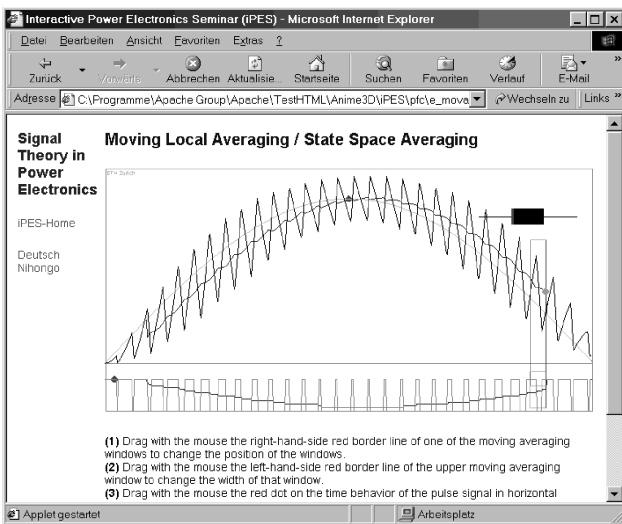
important influence on the circuit's function can be changed. This helps the student to focus on the main theory. The graphical user interface is very simple and self-explaining. Some of the applets are written similar to a computer game where the student has to control a system within a certain time and, for example, a current error rms value is calculated as a quality criterion of the student's performance. The underlying idea is to get the student involved in an emotional way what does improve the learning ability.

The iPES Java applets are presented with a minimum of text because many students dislike reading large text blocks on a screen [21]. The remaining text is about how to change parameters of the applet, and not about power electronics theory. Explaining the theory is still up to the teacher.

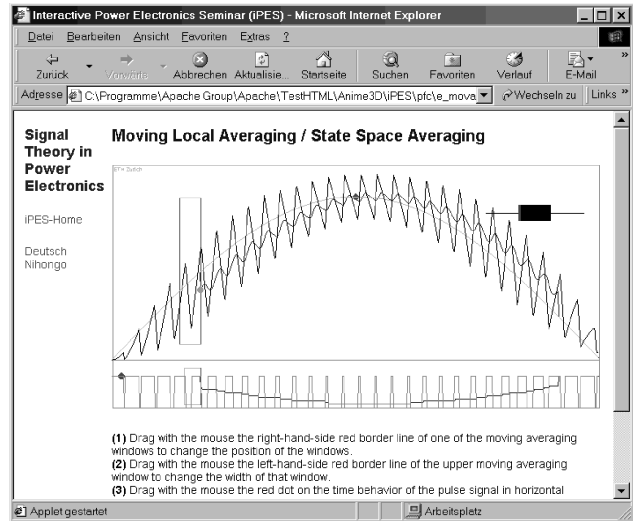
The applets are used with laptop and beamer in the course of lectures in the classroom in order to show basic concepts in power electronics. The students are provided with a textbook and also with a CD ROM for convenient off-line usage of iPES. The students are told to learn with the applets at home and to repeat what they have seen in the lecture. Furthermore, there is one lecture in a computer room where the students do get a introduction into iPES.

In the following a few examples of iPES-applets are shown in more detail. All applets are interactive and animated what is difficult to describe with text and static pictures. To get a more detailed understanding one should visit the iPES webpage.

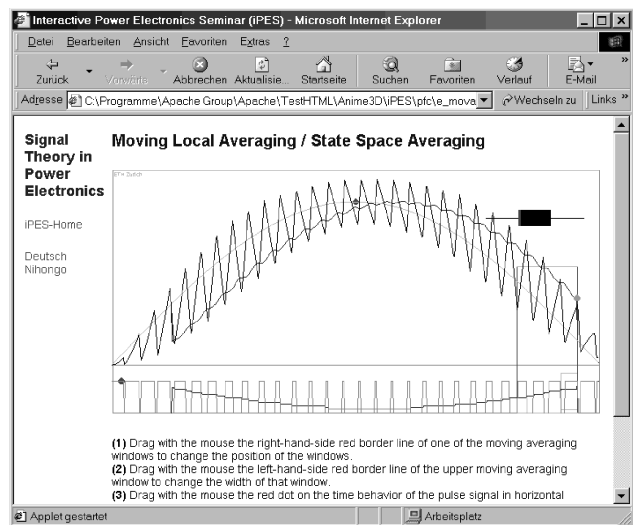
6.1 Example Moving Local Averaging / State Space Averaging



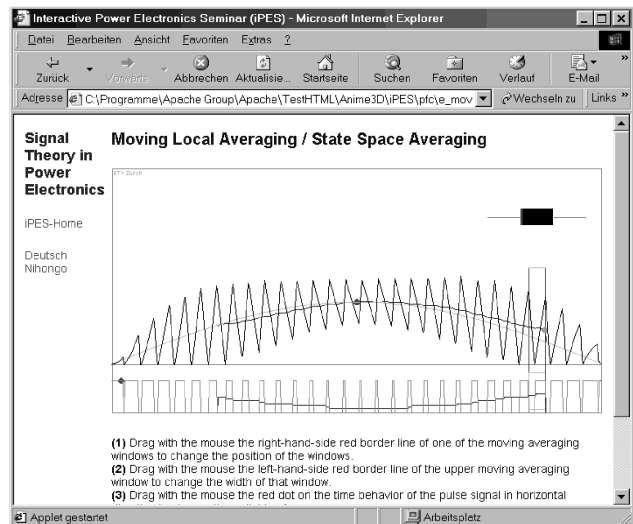
(a)



(b)



(c)

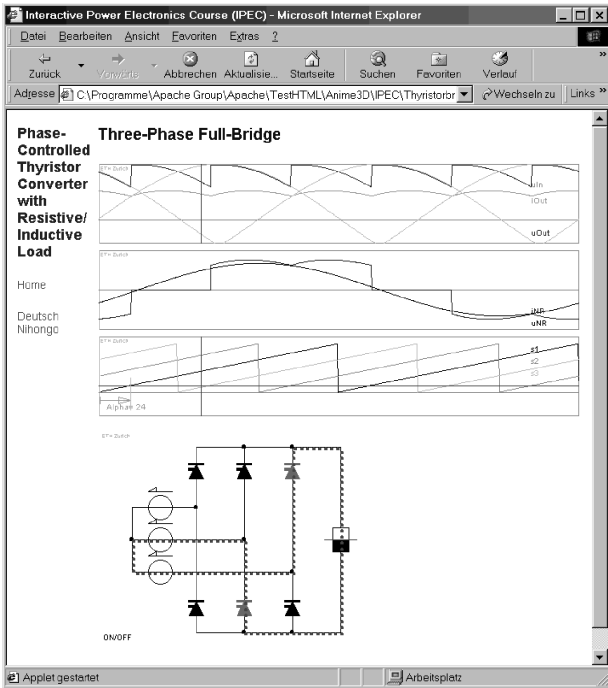


(d)

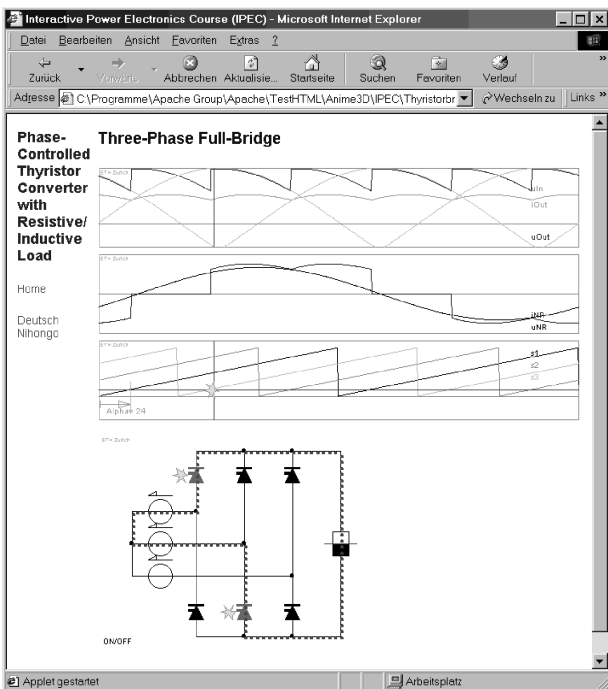
Fig.1: (a) The averaging window's width of one pulse period results in a smooth filtering and small phase shift. (b) With the averaging window's width a little bit larger than one pulse period a ripple occurs. (c) A large averaging window filters the ripple efficiently but results in a large phase shift. (d) Reduced amplitude.

For calculating conduction and switching losses of PWM converter systems, local averaging is a very useful mathematical concept. The basic idea is to take the average values of (squared) currents and voltages over one switching period what does eliminate the switching behavior. The resulting continuous local average values can then be treated further analytically.

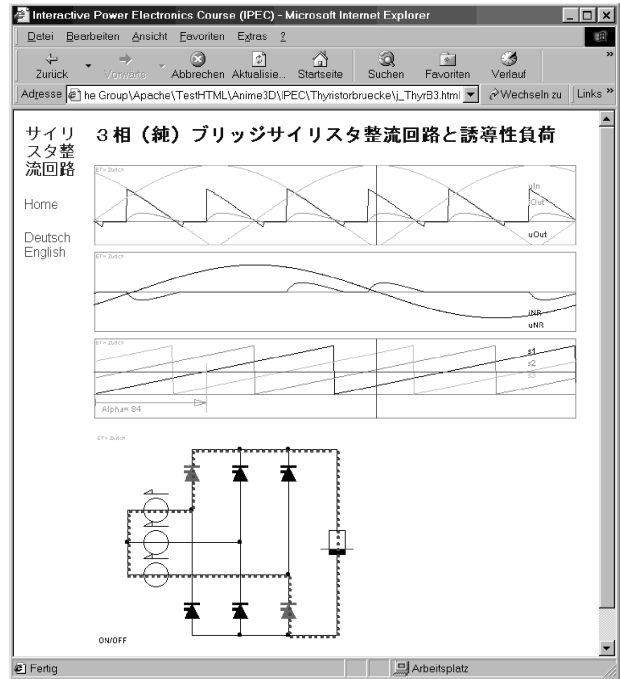
The concept is based on quite abstract mathematical theory. Also, often the students do find it difficult to understand the difference between a local average over a pulse period and a global average over, e.g. a mains period.



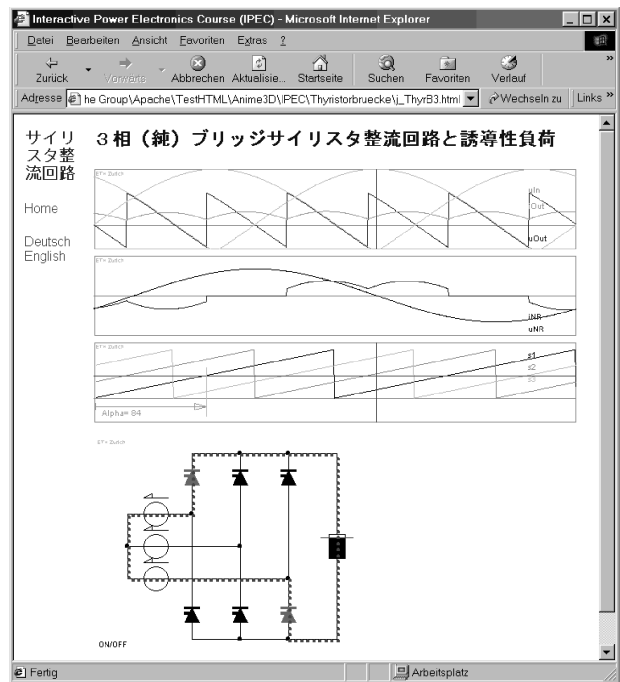
(a)



(b)



(c)



(d)

Fig.2: (a) Mixed load, small control angle, thyristors 3 and 5 do define the current paths. (b) Vertical time-marker dragged into next sector results in triggering (animated trigger signals) of thyristors 1 and 5. (c) Increased resistive load and control angle close to 90° (d) Increased inductive load. The languages describing the applets can be selected as German, English and Japanese.

The applet of Fig.1 does give the student a smooth introduction into the field of local averaging which is also of importance for controller dimensioning (state space averaging) by visualizing the mathematical concept. In Fig.1(a) at the right-hand-side the averaging window is

shown. The student can set the width of the averaging window by dragging the left-hand-side border line of the window. The position of the window can be changed by dragging the right-hand-side of the border line of the window. The value resulting from averaging of the current inside the window is drawn as shown in Fig.1(a).

In Fig.1(a) the width of the window is set as approximately one pulse period which results according to theory in a very smooth filtering. In Fig.1(b) the width of the window is a little bit larger than one pulse period resulting in a remaining switching frequency ripple. If the window's width is a several pulse periods the average value is smooth but there is a large phase shift of the output signal as shown in Fig.1(c).

Further possibilities provided by the applet are changing the switching frequency by dragging the red dot on the time-behavior of the pulse signal (left-hand bottom), changing the ripple amplitude by dragging the left-hand-side border line of the inductor symbol, and changing the amplitude of the current fundamental by dragging the red dot on the peak of the time-behavior of the current (Fig.1(d)).

The student can verify several theoretical issues with the Java applet in a simple way, the graphical user interface is very easy to use, and all effects are visualized.

6.2 Example Three-Phase Full-Bridge Phase-Controlled Thyristor Converter with Resistive/Inductive Load

In the Interactive Power Electronics Seminar (iPES) some basic phase-controlled thyristor converters are available. In the following, as an example, the three-phase full-bridge thyristor-converter is discussed in detail.

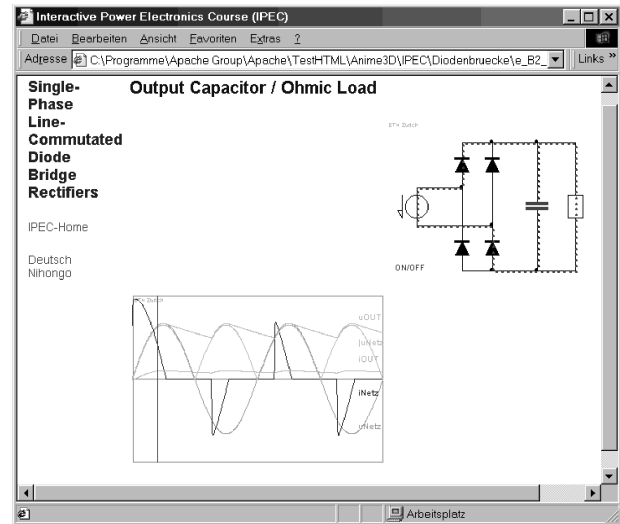
Basically, three different values can be defined by the mouse as shown in Fig.2:

(1) The vertical time-marker (top diagram and third diagram) can be dragged by the mouse and defines the actual state of the current flow as shown in the power circuit picture (bottom), where the conducting thyristors do change their color. When the time-marker is dragged into a section where a new thyristor pair starts to conduct current, the activated thyristors are animated with a "firing-signal" (as shown in Fig.2(b) in the power-circuit picture with thyristors 1 and 5). This animated "firing-signal" is also shown in the third diagram which gives the time-behavior of the signals which do define the thyristor firing and/or control angle by the intersection of sawtooth-signals (which are synchronized to the mains voltage) and the horizontal line.

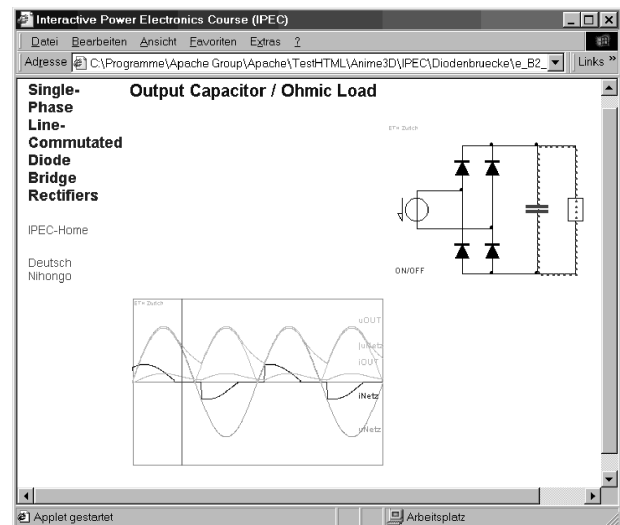
(2) The control angle can be changed by dragging the horizontal red line in the diagram of the control-signals (third from the top). This horizontal line defines the firing

of the respective thyristor pairs. In Fig.2(a), (b) the control angle is 24° el. while in Fig.2(c) and Fig.2(d) the control angle is 84° el.

Giving the time-behavior of the control signals (third diagram) is useful since many students have difficulties to understand how the trigger-signals of the thyristor-pairs are generated. Changing the control angle causes immediate calculation of the new time-behaviors of all voltages and currents in the other diagrams.



(a)



(b)

Fig.3: (a) Actual current paths are shown in the power circuit picture. (b) By clicking the capacitor its capacitance can be changed. E.g., reducing the capacitance does change the time-behavior of input current and output voltage accordingly.

(3) The ratio of the resistive and inductive component of the load can be changed in an intuitive way by dragging the red line in the load-symbol (black/white rectangle) in the power circuit picture (bottom). While in Fig.2(a), (b) the ratio is about 1:1, in Fig.2(c) there is mainly resistive load so that the output current does become discontinuous.

In Fig.2(d) the load is mainly inductive which results in more constant output current.

In summary, on a single web page all current-, voltage- and load-conditions of the quite complex three-phase full-bridge thyristor-converter can be demonstrated effectively.

6.3 Example Single-Phase Line-Commutated Diode Bridge Rectifier with Output Capacitor / Resistive Load

The single-phase diode-bridge rectifier with output capacitor is a standard circuit of power electronics. The diagram in Fig.3(a) shows the time-behavior of input current, output voltage and other important values. The vertical time-marker can be dragged by the mouse, the actual selected current flow is shown in the picture of the power circuit. The current flow is visualized by moving colored points. In Fig.3(b) the vertical time-marker is in a position where there is no input current and the resistive load is fed by the output capacitor (as shown in power circuit in Fig.3(b)).

Students often face difficulties in understanding why the output voltage of such a system is said to be approximately constant. Here, by simply clicking the capacitor in the power circuit picture with the mouse (and keeping the mouse-button pressed) the capacitance of the capacitor can be increased or decreased. The new voltage and current shapes in the time-behavior diagram are calculated and adjusted immediately. This makes it very easy to understand why increased capacitance results in more and more "constant" output voltage while the input current is forming sharp peaks. The circuit behavior for small output capacitance is shown in Fig.3(b).

7 Summary

In times of rapid changes of technologies it is essential for companies to provide employees with the possibility of updating their knowledge on a regular basis. One approach for efficient education in terms of quality, effectiveness, time and costs is "E-Learning".

In this paper a new operating-system-independent E-Learning software-tool iPES to be used for education in power electronics and electrical machines has been introduced. iPES can be employed via the Internet (available at www.ipes.ethz.ch in English, German and Japanese) or via a CD-ROM due to the combination of HTML text, Java applets and XML. iPES does simplify teaching when used with a laptop and beamer in the lecture room and it does simplify the studying of 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.

Furthermore, other projects and approaches of education in power electronics which are based on information technology are discussed in the paper. Such concepts do include animated and/or media-extended slide-shows, numerical circuit simulation in education, web-based content and web-based simulation in power electronics.

References

- [1] Uwe Drofenik and Johann W. Kolar: iPES - *Interactive Power Electronics Seminar* available at www.ipes.ethz.ch.
- [2] Uwe Drofenik, Johann W. Kolar, Peter J. van Duijsen, and Pavol Bauer: *New Web-Based Interactive E-Learning in Power Electronics and Electrical Machines*. 36th IEEE Industry Applications Society Annual Meeting, Chicago, Illinois, Sept. 30 – Oct. 4, 2001.
- [3] R. Ubell: *Engineers turn to E-learning*. IEEE Spectrum, Vol.37, No 10, pp. 59-63 (2000).
- [4] B.H. Chowdhury: *Power Education at the Crossroads*. IEEE Spectrum, Vol.37, No 10, pp.64-69 (2000).
- [5] www.microsoft.com/office/powerpoint/
- [6] www.adobe.com
- [7] Ned Mohan's links on www.pels.org/Comm/Education/Tutorials/tutorial.htm
- [8] Michael Karweit: *A Virtual Engineering/Science Laboratory Course*. www.jhu.edu:80/~virtlab/virtlab.html
- [9] <http://bwrc.eecs.berkeley.edu/Courses/IcBook/SPICE/>
- [10] <http://bwrc.eecs.berkeley.edu/Courses/IcBook/tools.html>
- [10] www.avanticorp.com/product/1.1500.65.00.html
- [11] www.simplorer.com
- [12] www.caspoc.com
- [13] www.java.sun.com
- [14] www.microsoft.com/net/default.asp
- [15] www.golden.com
- [16] www.microsoft.com/office/excel/default.htm
- [17] Flavio A.S. Goncalves and Carlos A.Canessin: *Java Applets for Power Electronics online*. www.dee.feis.unesp.br/gradua/elepota/ajuda/applets.html
- [18] Flavio A.S. Goncalves and Carlos A.Canessin: *Java Applets for a WWW-HTML-Based Course in Power Electronics*. Power Electronics Specialists Conference (PESC), 2001. IEEE 32nd Annual , vol.1, (2001) p.85–90.
- [19] Large collection of Java applets for engineering divided in various engineering categories at www.jars.com/jars_categories_java_science.html
- [20] Crutchfield, S.G. and Rugh, W.J.: *Java applet demonstrations in Signals, Systems, and Control*. <http://jhu.edu/~signals/>
- [21] Crutchfield, S.G. and Rugh, W.J.: *Interactive Learning for Signals, Systems, and Control*. IEEE Control Systems Magazine , Volume: 18 Issue: 4 , Aug. 1998 p. 88 –91.
- [22] Hao Shi: *Java in Electr. Engineering*. www.eecircle.com/
- [23] Changyeon Won: *Physics Java Applets java language for simple physics simulation*. <http://socrates.berkeley.edu/~cywon/>
- [24] Venkat Ramaswamy: www.ee.uts.edu.au/~venkat/pe_html/contents.htm (www.powerdesigners.com/InfoWeb/resources/pe_html/)
- [25] J.C. Principe, N.R. Euliano, and W. C. Lefebvre: *Innovating Adaptive and Neural Systems Instruction with Interactive Electronic Books*. Proceedings of the IEEE, Special Issue: Electrical & Computer Engineering Education, Vol.88, No 1, pp.81-95 (2000).