Multimedia Based E-learning Tools for Dynamic Modeling of DC-DC Converters

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Abstract – **Exploiting the recent achievements of the information and communication technologies, a new e-learning initiation entitled Yoto project was launched in 2004. On longer run its most important objective is to build up and maintain an electrical engineering knowledge base, on shorter run it helps giving more and more publicity to some relevant fields, especially power electronics, drives and motion control. The multimedia rich content can be utilized in the high level academic education, in the industrial vocational trainings and also in supporting the circuit and system design specialists by fast interactive tools. This paper presents a new e-module attached to the Yoto project about the dynamic operation and modeling of dc-dc converters.**

Keywords: E-learning, power electronics, dc-dc converters, dynamic modeling, vocational training, interactive animations, multimedia.

I. INTRODUCTION

As newer and newer solutions were carried out in the field of the information technologies and multimedia in the last several years, new claims and efforts could be noticed relating to modernization of the engineering curriculums. The software technologies and modeling methods provide a solid background to construct up-to-date knowledge bases in order to promote relevant fields and to enable the access to the novel research and development results.

Earlier, due to the lack of the technological background and the inadequate bandwidth of the communication network, mostly the text-based curriculums were spread. However, this trend is currently shifting and probably in the subsequent years the text-based models will mostly be replaced by the multimedia and especially the interactive type models. These days severe efforts are on the strict separation of the data content from the mode of the presentation (e.g. XML based data sets and documents and Extensible Stylesheet Language Transformations (XSLT)), which facilitates a much more effective utilization of the existing data and information. The interactive, multimedia based knowledge bases open up wide opportunities for the academic education, the industrial vocational trainings and also for the practicing engineers. The users themselves are expected to reinvent the curriculum rather than only to read about them.

As the e-learning has recently started becoming more and more popular, several institutes started developing partly multimedia based education materials also in the field of power electronics and drives. The applied technologies and standards are diverse but mostly the client-side technologies are preferred, because this way the content can be utilized via high speed network and it can also be distributed on CD/DVD ROMs. There are numerous new technologies and standards to build dynamic content. In many cases Java applets and/or Macromedia Flash objects are embedded in HTML or XHTML pages providing the interactive surfaces, although sometimes JavaScript and VB Script are used to make the pages dynamic. The .NET technology has also been becoming more and more popular, since its launch by the Microsoft in 2002.

A detailed overview of the recent efforts on the e-learning content development can be found in [1]. One of the first initiations was carried out by J. Kolar and U. Drofenik at the Swiss Federal Institute of Technology Zurich, in Switzerland. The Interactive Power Electronics Seminar (IPES) is widely known [3-4]. It contains interactive e-learning tools for power electronics and electrical machines: signal theory in power electronics, theory of three phase systems, dc-dc converters, several types of diode and thyristor rectifiers with different supply and load conditions, dc drives, power factor correctors, resonant converters, one and three phase converters, matrix converters, Vienna rectifier, thermal problems in power

electronics, heat transfer models, fundamentals of electric and magnetic fields, etc.

The Inetele project has been carried out within the frames of Leonardo da Vinci Programme sponsored by the European Union [5-7]. With the participation of altogether twelve European institutes, new multimedia based curriculums were developed in the following fields: CAD in electrical engineering, electrical machines and apparatus, microelectronics, industrial and power electronics, electric drive systems and their applications, control of technological processes, influence of converters on environment and power quality improvement.

There is a particular feature of the electricity and electronic circuits, namely that the quantities (voltage, current, flux, etc.) are usually not directly perceptible, only through some measuring equipments. At the design of the animations usually one of the most complicated task is to visualize the relevant electric quantities and characteristics. An interesting idea about the modeling of the electric circuits is shown in [8]. The novelty of the animations is that instead of using the conventional 2D representations of the electric circuits, 3D ones are applied. The role of the third (z) axis is to present the voltage alterations in the circuit.

Another curriculum was prepared in the frames of a Tempus Joint European Project with the participation of three European universities [9]. The main topics are transformers, DC motor-generator, induction machines, synchronous machines, brushless machines, stepper motor, reluctance drive, actuators, linear motors, heating and cooling, bridge-inverters, etc.

Further interesting results of this area were published in [10-13].

II. THE YOTO PROJECT

The Yoto project was launched in 2004 with the most important objective to promote and popularize the electrical engineering science, especially the fields of power electronics and drives. The multimedia rich curriculums are usually quite popular, particularly in the case of the young engineers and students. The concept of the Yoto project was settled around the following key ideas:

- To popularize the electrical engineering sciences.
- To promote the high quality academic education of the electrical engineering field.
- To support the regular vocational trainings of the companies for the qualified engineers.
- To increase the flexibility of the education regarding the time and the location.
- To mitigate the geographical and regional inequalities by making accessible up-to-date research & development results.

- To support the education of handicapped students.

The simplified architecture shown in Fig. 1 contains the framework and the separate e-modules as the main building blocks. A more detailed description of the framework can be found in [20], now a short overview is given. Conceptually, special care was taken at the development of the architecture and the framework to keep the system for the users simple and flexible. Simplicity refers especially to the graphic user interface; the framework and the modules are designed for use without any special knowledge on the computer science or software technologies. The central component of the architecture is the solid and reliable framework, which is capable to host and control the modules, produced by diverse technologies (Fig. 1). The framework can access relevant data from the configuration database. The users can reach up-to-date information and news. The architecture highly supports the multilingual module content, implicitly the text and speech.
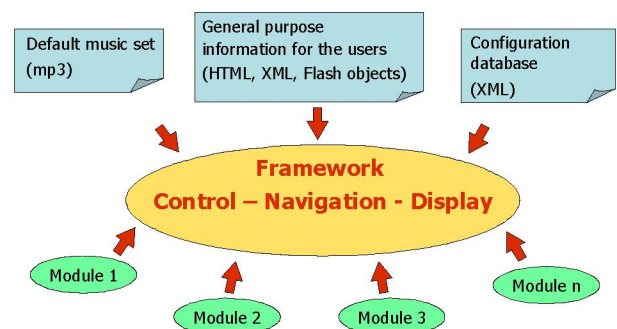

Fig. 1 Yoto project: basic architecture

The general module structure is shown in Fig. 2. The basic settings are stored in the configuration database, containing relevant information on the separate modules, e.g. the selectable languages, the availability of speech and music files etc.
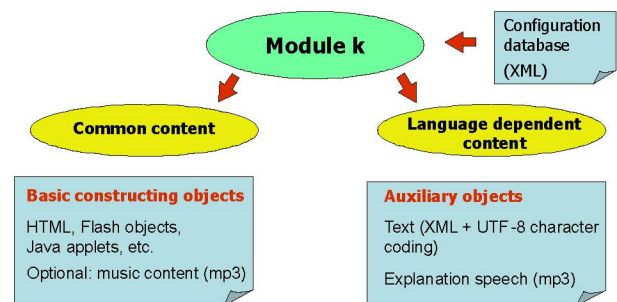

Fig. 2 Module structure

The module content is strictly separated into two parts, the so called common content (or language independent content) and the language dependent content. In this manner the internationalization becomes much simpler, since only the language-dependent files should be modified (text and speech) during the translation, while the main technical content remains

unchanged (animations, interactive tools, etc.). One screen of the module "*Classification and Steady-state Operation of DC-DC Converters*" presented earlier in [2] is shown in Fig. 3, offering interactive tools for steady-state operation of dc-dc converters.
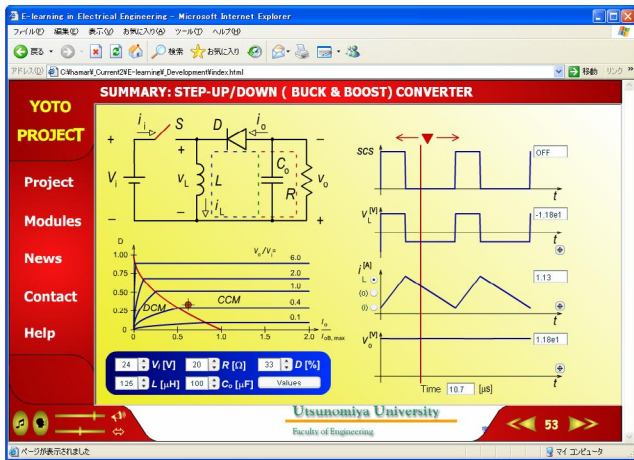

Fig. 3. Interactive tools for dc-dc converters

It allows the alteration of altogether five input/control parameters and points out how it influences the steady-state operation and how it affects on the internal state-variables and on output quantities.

III. DYNAMIC MODELING AND LINEARIZATION OF DC-DC CONVERTERS

The recently developed module focuses on the dynamic modeling of dc-dc converters. The module starts by highlighting the nonlinear time-varying operating mode of switching converters, which demands the use of simplified models in order to expedite the design of power electronics systems. Since the use of linearized models for analysis is mature in power electronics, it allows the direct application of conventional small-signal approaches and actually most engineers are trained to use linear methods; the objective of linear modeling is introduced. This introductory part ends by an application example for closed-loop stability as basic design concern in practical power electronics systems (Fig. 4).

The module focuses next on two particularly useful modeling approaches:

1. Continuous-time averaging approach
2. Discrete-time iterative mapping approach

The averaging approach is introduced first and discussed in this paper, as probably it is the most widely adopted modeling approach for switching converters, published by R. D. Middlebrook in the 1970s. It effectively removes the time-varying dependence from the original time-varying model and

produces a continuous-time state equation that contains no time-varying terms.
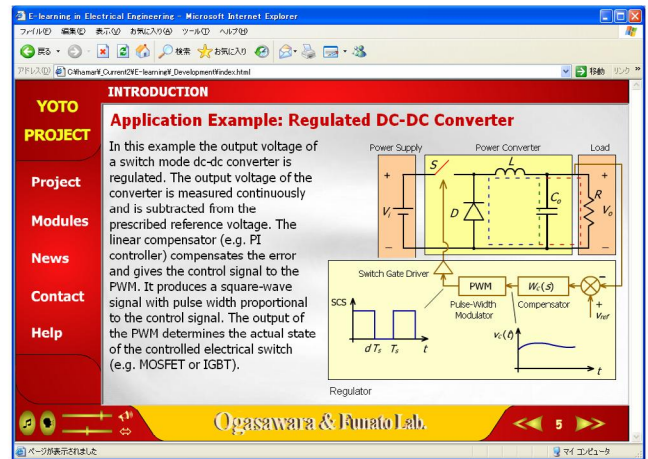

Fig. 4. Application of linear converter models

The corresponding part of the module describes the modeling process (Fig. 5), in which the state equations of all the possible stages are first written down, and the final model is simply the weighted average of all these state equations. The weightings are determined from the relative durations of the stages, which are illustrated through the red-colored "flow" of time.
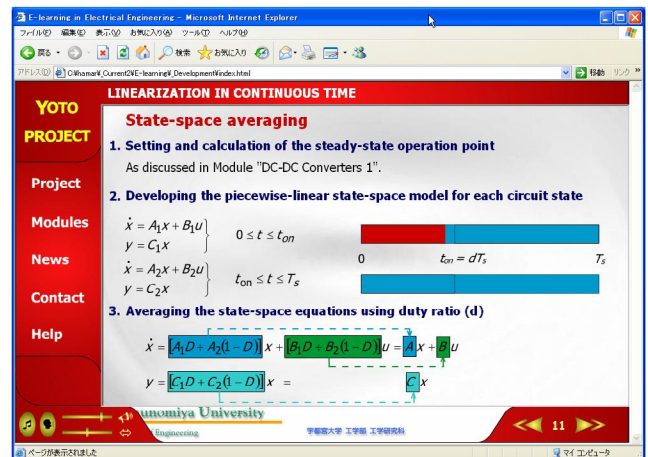

Fig. 5. Key idea of modeling by continuous-time state-space averaging

The module proceeds with the next step of the modeling process, which is the assumption and corresponding substitution into the equations for each of the new variables (which actually represent local averages of the original instantaneous variables) of a constant (dc) nominal component and a small perturbation component. Finally, the system is linearized around the steady-state operating point by expanding the equations, neglecting second-order perturbation terms and subtracting the respective steady-state equations (Fig. 6).
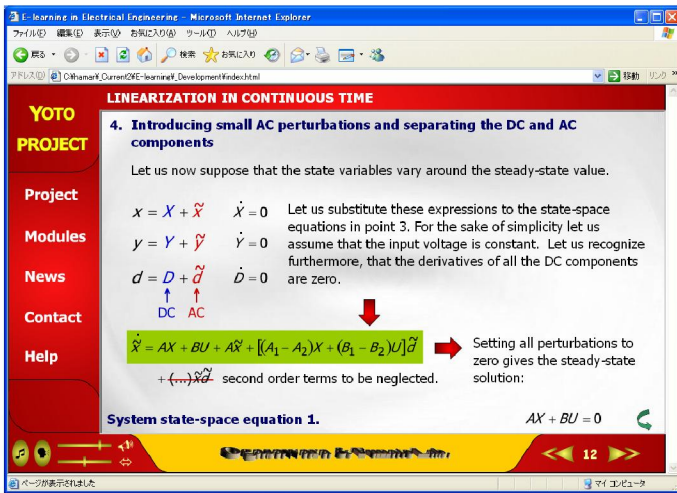
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Fig. 6. System perturbation and substitution of ac and dc terms in the system equation

After some additional steps this part of the module, describing the continuous-time linear modeling by state-space averaging, ends by expressing the control-to-output transfer equation, obtained by taking the Laplace transforms of the linear differential equations representing the small signal (ac) behavior of the converter (Fig. 7).
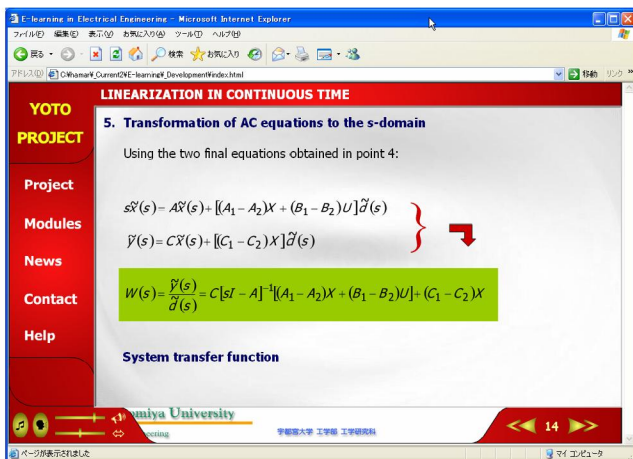

Fig. 7. Achieving the objective of linear modeling by continuous-time state-space averaging

After the discussion of the general state-space averaging method, its practical benefit is shown for the step-down (buck), step-up (boost) and step up-down (buck & boost) converters (Fig. 8). The process is shown in a detailed manner for each converter yielding the state space matrix equations and the small signal transfer functions.
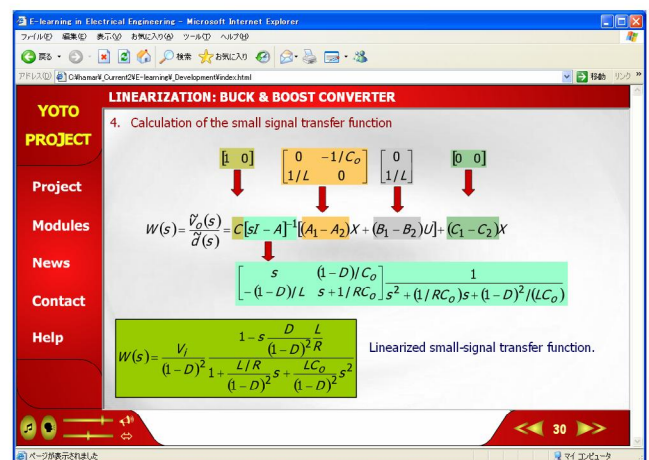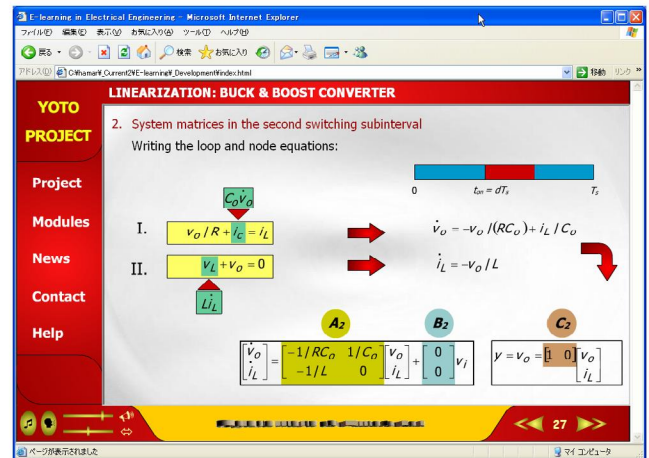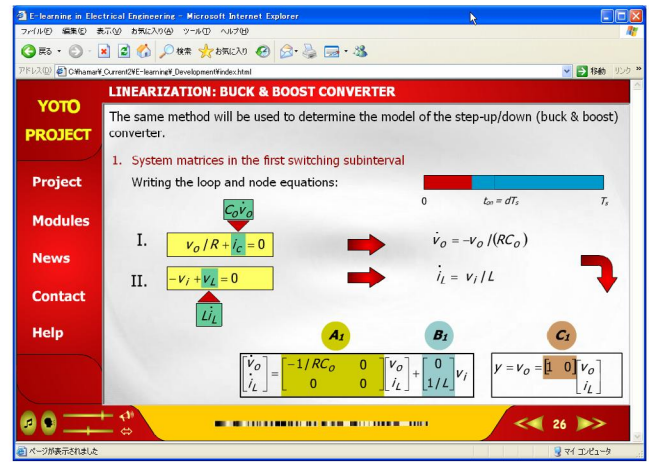

Fig. 8. Screens on practical use of linear modeling at the buck & boost converter

Summarizing the continuous time modeling of dc-dc converters, interactive tools were developed (Fig. 9...Fig. 12). On one hand they promote the understanding of the results provided by the linearization and the effect of the input and converter parameters on the dynamic model and second they are also devoted to support the practicing design engineers by fast modeling tools. They facilitate the easy change of the following input- control- and circuit parameters: input voltage,

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duty ratio, load resistance, choke inductance and output capacitance. Linear models both in the state-space and in the s-domain is being automatically and suddenly calculated and shown on the basis of the adjusted parameters. It can be well traced, how the model alters as any of the parameters varies. This functionality is available by pressing the "*Model*" button in the bottom right corner (Fig. 9…Fig. 12). Since these converters usually operated in continuous conduction mode (CCM), therefore the models are also calculated for these operation conditions. Whenever the user changes the parameters such that the operation becomes discontinuous, a warning on this situation will be shown and no model will be built. However the values of the most relevant steady-state parameters (e.g. voltages and currents) can still be checked in the middle left side (Fig. 9 and Fig. 12). The relative position of the steady-state operation point in the operation domain can also be traced after clicking on the "*Characteristics*" button (Fig. 10 and Fig. 11). The switch in the converter strives to turn on and off proportionally to the duty ratio adjusted. The path of the current in the converter is also shown both in continuous and discontinuous conduction modes.

On the right side of the screens the graphical representations of the models are indicated. User can select between the pole-zero map and the bode plot of the system. In either case the plots are updated suddenly for any modification of the system parameters. It facilitates a good insight into the dynamic behavior of the converter and helps in the interpretation of the dynamic model. Switching among the plots is available by clicking on the button on the upper right side. In case of the bode plot, by moving the vertical red guide left and right, the values of the frequency, magnitude and phase angle are displayed in the corresponding white text boxes. If the visibility of the plot is inadequate, zoom function is provided by pressing the small white "*Zoom*" buttons. The pole-zero map is devoted to give insight how the poles and the zeros of the system are wandering as the parameters are being varied. Moving the mouse cursor over the map the real and imaginary components of the cursor position are shown on the bottom. For showing the exact coordinates of any pole or zero on the complex plane, the user should only move the mouse cursor above it (its color will change to orange) and click on it.

The dynamic model of the buck converter has a qualitative difference in comparison with the boost- and buck & boost converters. Namely, the converter does not have any zeros but two poles which can either be a complex pair or two real poles. By changing the system parameters adequately, both types can be realized and observed. The boost and buck & boost converters have an additional real zero on the right half plane, which has normally significant influence on their dynamic behaviors and also on the stability of the closed loop system.
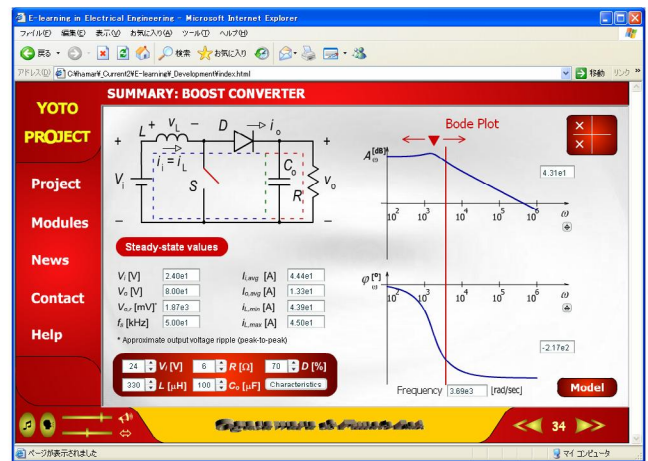

Fig. 9. Interactive modeling tools for the boost converter: Bode-plot and steady-state parameters in tabular form
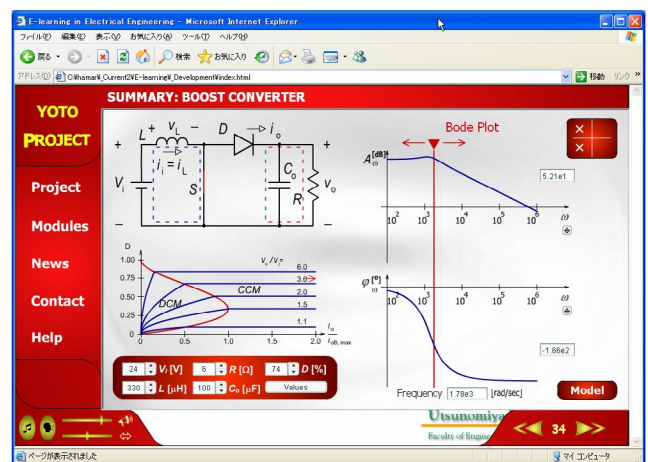

Fig. 10. Interactive modeling tools for the boost converter: Bode-plot and steady-state characteristic curves
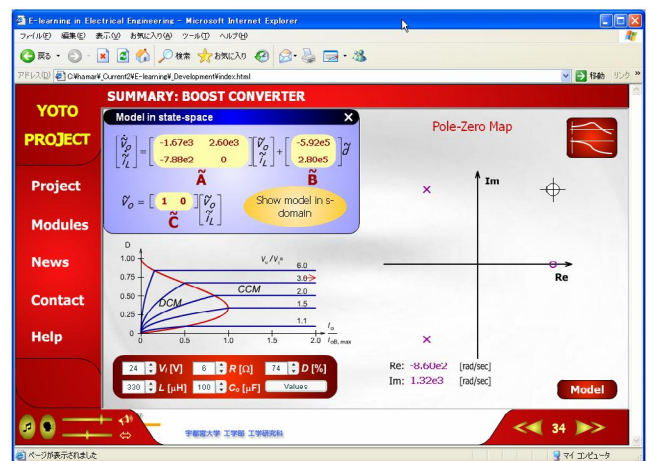

Fig. 11. Interactive modeling tools for the boost converter: Pole-zero map (right) and state-space model in a separate window
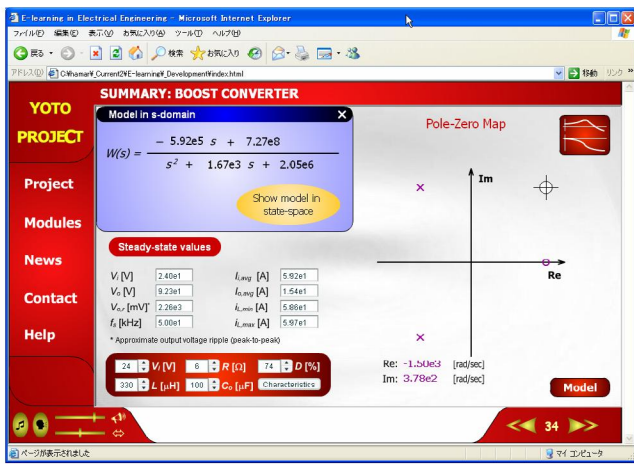
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Fig. 12. Interactive modeling tools for the boost converter: Pole-zero map (right) and transfer function in the s-domain in a separate window

IV. CONCLUSIONS

Nowadays a tendency can be realized in numerous fields of the engineering science tending to extend the available curriculums from the text oriented models toward the interactive models. The basic objective of the Yoto project is to exhibit an electrical engineering knowledge base, laying special emphasis on power electronics and drives. The basic architecture was shortly outlined along with the basic building blocks; the role of the framework and the separate e-modules were briefly explained. The architecture strongly supports the multimedia rich, multilingual content and put the widely used, platform independent standards and technologies forward. Widening the available content, a new e-module relating to the dynamic modeling of the dc-dc converters was presented. The module explains the continuous and discrete-time modeling and linearization of the basic converters. In this paper the continuous-time modeling was discussed. These tools can be widely employed in the academic and industry level education and especially the interactive tools also in the control design.

ACKNOWLEDGMENT

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