Simulation and Animation of Power Electronics and Drives, Requirements for Education

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Abstract: In this paper simulation for educational purpose in the field of power electronics and electrical drives is discussed. First the standard demands for a simulation packaged are given and second the extra demands for educational use are discussed. Important demands for education are visualization of the simulation results as well as an open interface to exchange data from one simulation package to another simulation package.

Keywords: simulation, modeling, education, animation, visualization,

1. Introduction

Simulation and animation often enrich modern education in the field of power electronics and electrical drive systems. There are several circuit simulation packages in use and each of them has some strong and some weak features.

Standard demands for simulation packages are:

- Fast simulation without convergence problems
- User friendly interface with schematic editor
- Multilevel modeling capability
- Detailed models of the semiconductor switches
- Link with modeling language (C/C++)

There are several simulation packages available. The best known are Spice, Saber, Matlab/Simulink, Caspoc, Simporer, EMTP, … Some of them fulfil the above mentioned requirements. This paper wants to give an answer to the question what more does the user want and show the latest development in the Power Electronic simulations.

The answer can be defined in two points:

1. Easy visualization of Simulation results
2. Open interface for data exchange for integrated simulation

2. Easy visualization of Simulation results

Animation based on interactive simulation is a way to go deeper inside a problem. There are various interactive approaches when it comes to teaching. The first approach was given by iPes[7] where interactive applets show the operation principles of power electronics converters. In the INETELE framework [8], the focus is broader and includes both theory and practice of power electronics and electrical drive education. The focus is more general and also exercises for self-study are given.
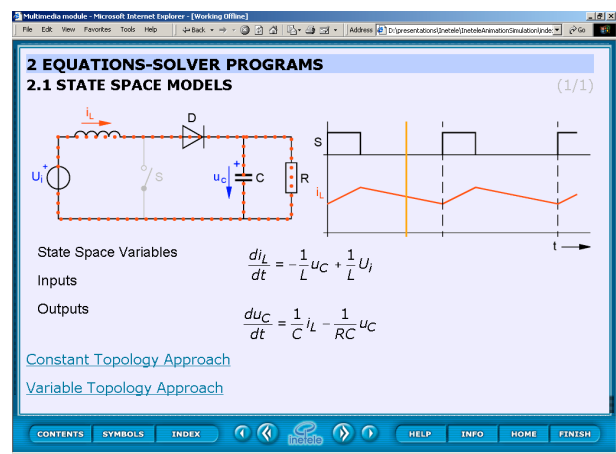

Figure 1: Buck converter operation rpinciple with equations in the INETELE framework.

The use of a general simulation tool is the only way to allow to go deeply inside the operating of a device and to understand the dynamic interactions between parameters. The simulation program, Caspoc [11] allows that the circuit is animated during the simulation. This gives insight in the behavior of the circuit during its operation. It is possible to follow the current path and see which switches are opening or closing. The voltage level is given numerically at each node, while a moving dashed line indicates the direction of the current. The color of the nodes and the current path are dependent on the level of the voltage and current. This visualizes the operation of the converter in detail. The user can interact with the simulation/animation by changing parameters during the simulation/animation and immediately see their influence on the circuit behavior.

The use of dedicated animation applets is presented in [7] and [8]. A more general approach can be found in [9].

The main features of power electronics system simulation are the large number of simultaneously occurring variables i.e. voltages and currents, in particular:

- the way they vary with time
- their polarities
- their mutual dependency (in particular the causal relations)
- their relation to the state of the circuit
- states of the individual switches
- control signals

To perform a simulation of the more complex system requests from the designer to follow very closely the simulation and run it more then once to understand the causal relations as summarized above. The designer in that case sits behind the computer and waits for one or other instant (action) to happen. Visualization of all variables becomes even more important. Therefore earlier animation is added to the simulation program. To simplify the process of visualization it is possible to use the so called 'Freeze and go back feature'.

The simulation results are stored in the computer and it is possible to use the time cursor and go back with the time. The state of the all switches, control signals and currents and voltages is shown again. The animation feature allows top following all the causal relations without sitting behind the computer during the simulation itself. In Figure 1 such a visualized animation with freeze and go back feature is shown, where the point in time of the animation is determined by a track-bar pointer.
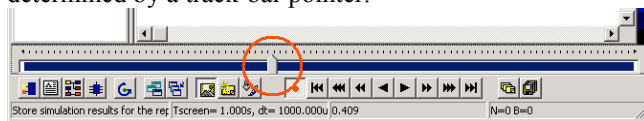

Figure 2: "Freeze and Go Back" track-bar pointer

3. Animation and Interactivity

Important for the basic education of power electronics and electrical drives, is the interactivity of the simulation/animation program. The user/student has to have the ability to influence parameters and/or conditions during the simulation/animation and thereby see the immediate effect of these variations in his simulation/animation results. In the following examples, simple applications are shown that, although the circuit/system under investigation looks very simple, shows the possibilities of interactivity that can be applied in a any simulation/animation. Figure 3 shows an animation where the current flow is in the circuit is influenced by clicking the switches in the schematic with the mouse pointer. An immediate response is given by the flashing on/off of the light bulbs and the analog meters. The interactive components, such as switches, keys, numerical inputs, etc are active during the animation. Animation objects, like analog meters, light bulbs, LED displays, rotating motors and mechanical components show the

response to the user. The colored wires indicate the current flow, where the color is given by the intensity of the current in Ampere.
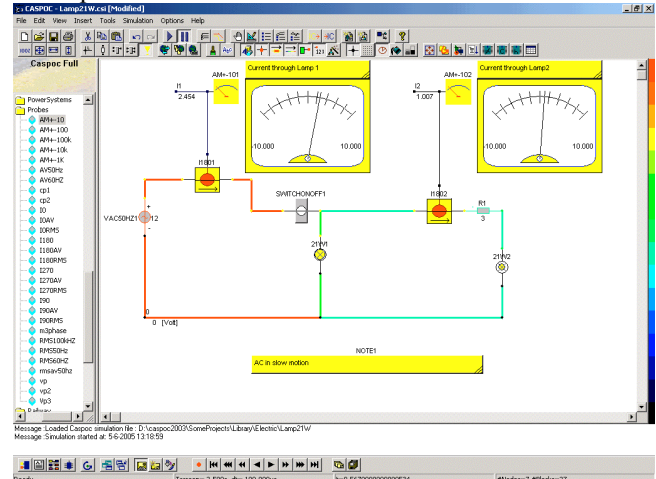

Figure 3: Animation of the current flow in a circuit.

To study the freewheeling of a diode in a Chopper, consider a simple animation like in figure 4.
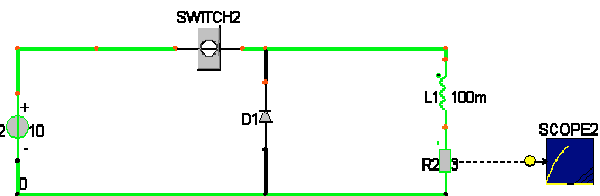

Figure 4: Animation of the current flow through the voltage source, switch, L and R.

Clicking the switch with the mouse pointer during the animation turns off the switch, see figure 5.
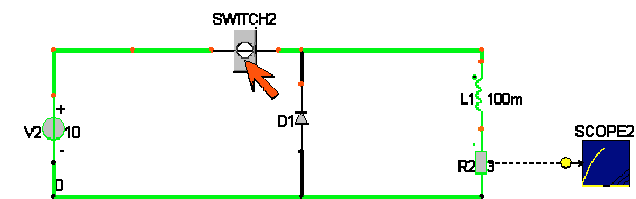

Figure 5: Turn off the switch during the animation with the mouse pointer.

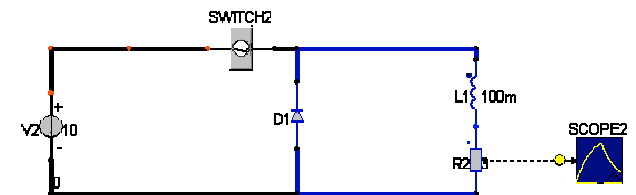After the turn-off of the switch, the freewheeling of the diode is visible in the animation, see figure 6.

Figure 6: Freewheeling of the diode after the switch is turned off.

To understand the basics of rectifiers, consider the simple animation in figure 7.
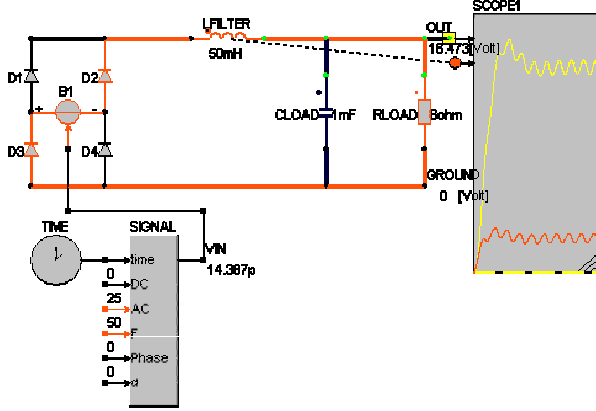

Figure 7: Current path in a rectifier.

The current path is shown during the animation and shows students the commutation process. The animation can be extended to any type of rectifier and line inductance can be included to study the overlapping of diodes during commutation. Using the "Freeze and Go Back" feature, the student can identify each time interval and see the voltages and currents at that moment in time.

Transients in mechanical drives during start-up are visualized with animated rotating components in figure 8:
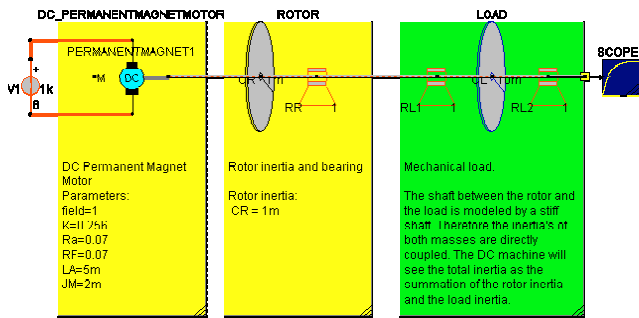

Figure 8: Permanent Magnet DC machine with mechanical load.

Second order effects, are visualized by the different angular positions and angular speeds of the two rotating masses.

Important for all animations and the understanding is the "Freeze and Go Back" feature. The student can visualize any point in time by dragging the track-bar pointer, see figure 2. To see the numerical values of the voltage and currents in his circuit, the student can move his mouse pointer over a component, see figure 9.
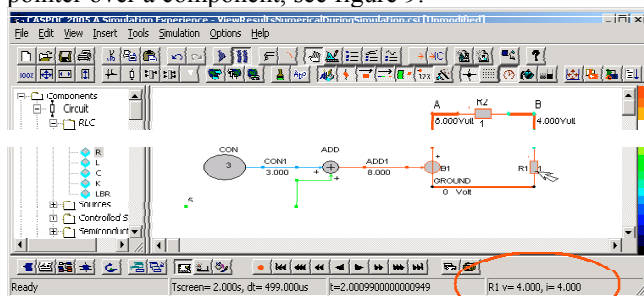

Figure 9: Measure voltage and current numerically.

Although the given examples are very simple, the same methodology can be applied to more complex structures, like for example, a three-level inverter see figure 22.

To study the behavior of electrical drives, the animation can help in understanding the non-linearity of certain types of machines, for example, Switched Reluctance Machines (SRM). In figure 10 the rotor angular position dependent inductance is shown.

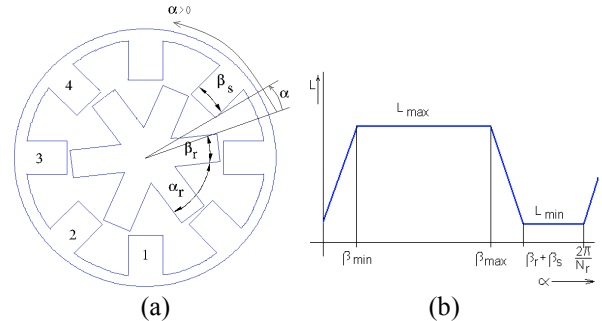(a)   (b)

Figure 10: a) Geometry of the stator and Rotor in a SRM, b) Non-linear rotor angular position dependent inductance of the SRM.

During the animation the position of the rotor is shown and the student can see the alignment between the stator and the rotor. The value of the inductance is displayed in time and can be correlated to the alignment. Using the "Freeze and Go Back" feature, he stuednt can see how the inductance varies with the alignment and how the control is based on the rotor position, see figure 11.
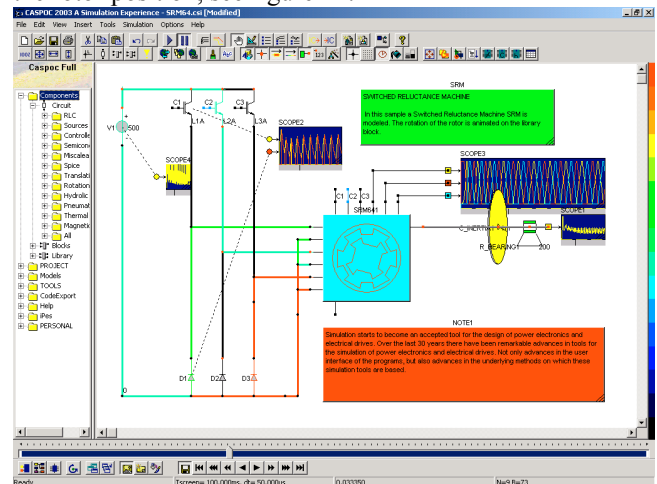

Figure 11: Animation of a SRM with inverter.

4. Open Interface for Integrated Simulation

Typical power electronics system analyses consist of many aspects and is multidisciplinary. These are, for example, parameters of magnetic actuators, parameters and precise models of semiconductor switches, electrical machine parameters, thermal effects, different control issues, packaging and parasitic effects as a result of different layout, to name a few. Designers are usually concentrating on one or more aspects, but the trend is clearly towards an integrated approach as depicted in Figure 12. The power electronics simulator is central in this case (simulator Caspoc). The interaction and data exchange with different

analysis and design tools is hereby necessary. Standard and open interface for data exchange is demanded from simulation software. In the following section some examples of such an open system are presented [12].
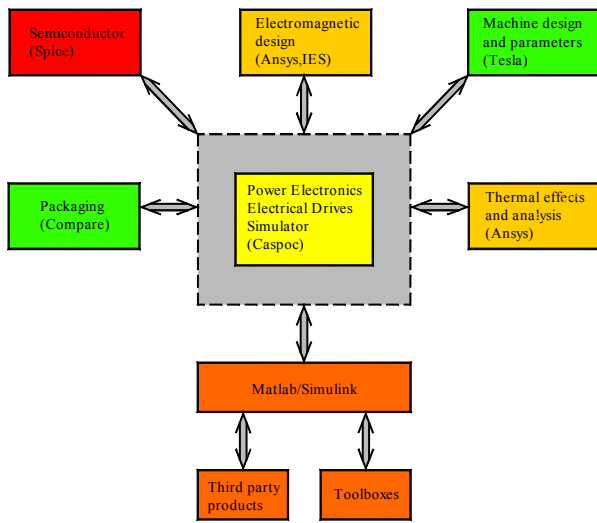

Figure 12: Integrated simulation approach, with couplings between different tools

The coupling of the network simulator (Caspoc) with Finite element analysis (FEM) is reported in [1] and [2].
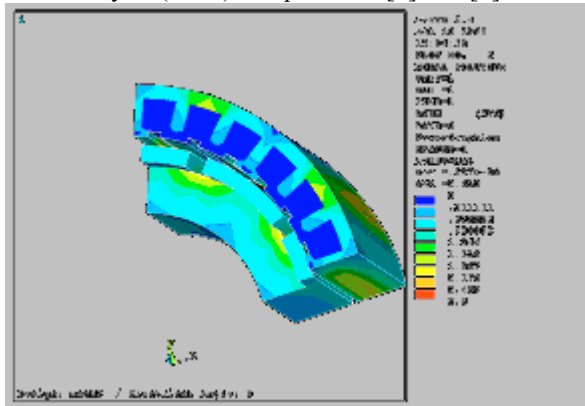

Figure 13: FEM model of a PMSM.

For the simulation the component parameters are necessary. Electrical machine and its parameters as a part of the drive forms here usually an unknown and non-linear. Using FEM [3], parameters for electrical machines are calculated from the geometrical structure and are dependent on rotor position and material properties, see figure 13 for FEM model of a PMSM. This way the simulation of a drive system can be performed before even a machine is build.

For Power Electronics the magnetic design becomes critical when it comes to efficiency and compactness of magnetic components. In [2] it was found that the inductance matrix parameters calculated by a 2D FEM calculation were significantly lower than those obtained from a 3D FEM calculation. This is due to the fringing flux in the 3rd dimension that is not calculated by a 2D FEM model, but is modeled correctly in a 3D FEM model, see figure 14.
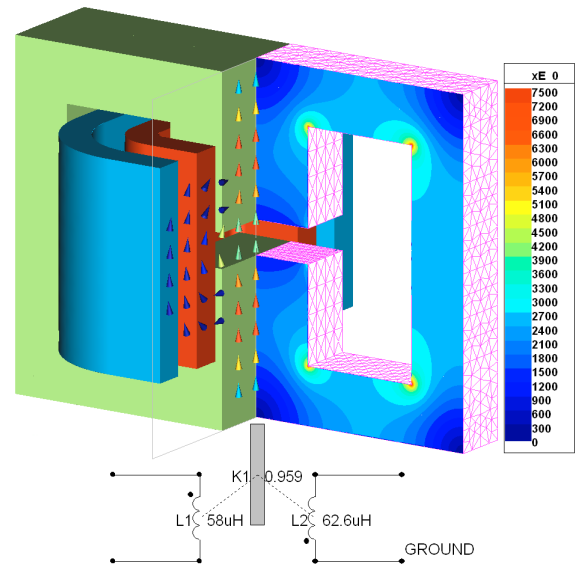

Figure 14: Obtaining the coupled-inductance from FEM for a circuit model.

Another example is the thermal effect. Thermal and electrical behaviors affect one another. The electrical characteristics of the device depend on its temperature distribution, at the same time the generated heat depends on the power loss (Fig.15to Fig.18).
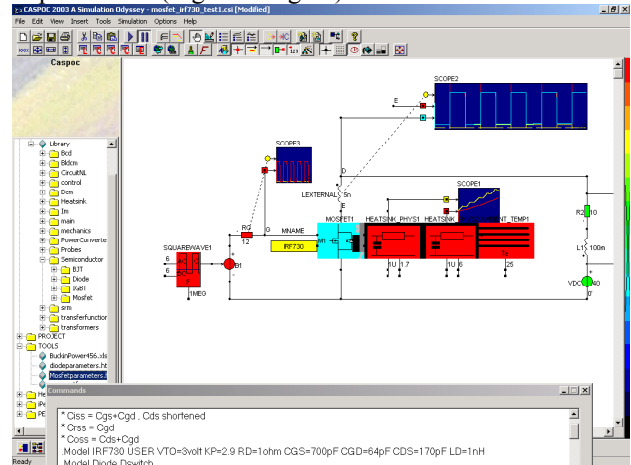

Figure 15 Thermal model in Caspoc

The different temperature of the elements results in different circuit parameters, especially for the on-resistance and transconductance of a Power Mosfet [4].
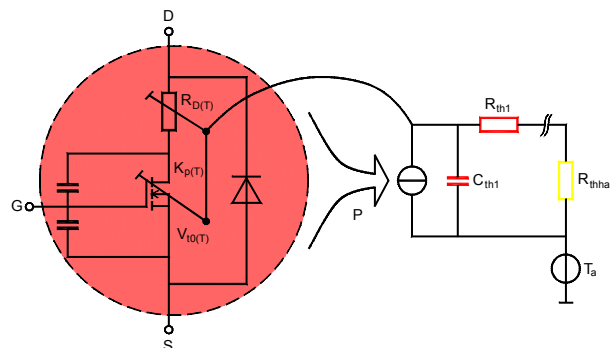

Figure 16: Nonlinear Mosfet Model with thermal heatsink model

An optimization of the design where the thermal issues were considered was not a common practice, when systems were large and efficiency was not of primary concern. With ever decreasing packaging dimensions become more important the thermal design becomes a part of the optimization of the total design [4].
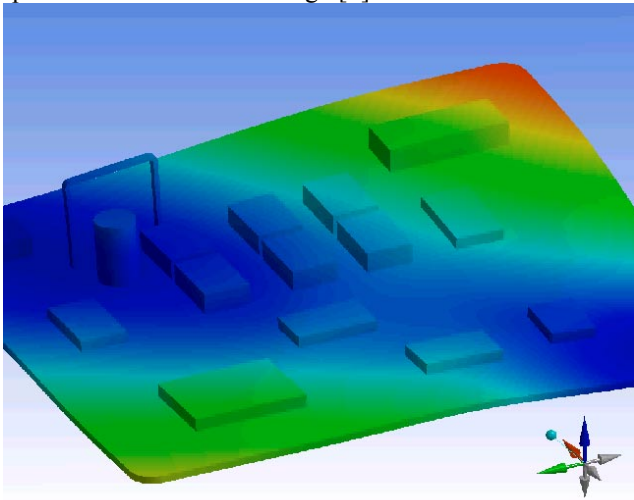

Figure 17 Thermal analysis in FEM

From the FEM analysis a thermal model can be constructed that is used in the circuit simulator.
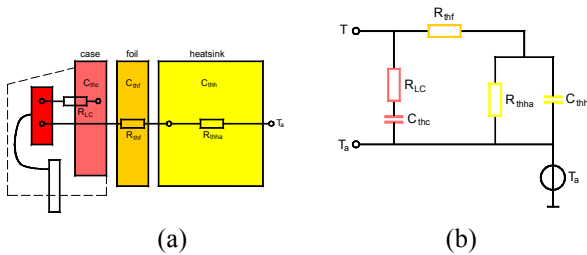

(a)   (b)

Figure 18: a) Thermal layers approximated from FEM. b)Equivalent thermal circuit model.

One of the strong features of Matlab/Simulink are the toolboxes such as the Control toolbox with detailed description of several control methods. For the simulation of complex controls Simulink has become the preferred platform during recent years. Modeling the control in Matlab/Simulink connected with the circuit simulator offers advantages.
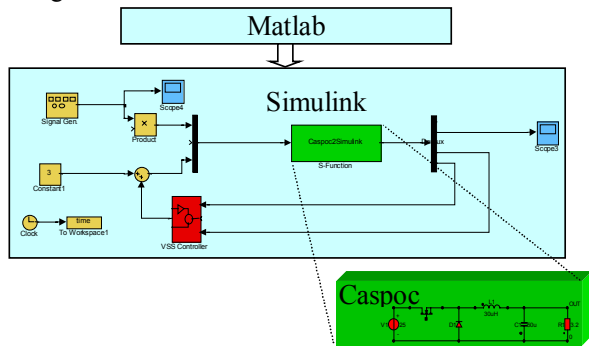

Figure 19 Coupling between Matlab/Simulink and Caspoc

The co-simulation between Matlab/Simulink (Fig.19) and the circuit simulator Caspoc (Fig.20) lead to a detailed simulation of a VSS (Variable Structure System) control. The results are demonstrated on discrete mode VSS with discrete-time sliding model control [5].
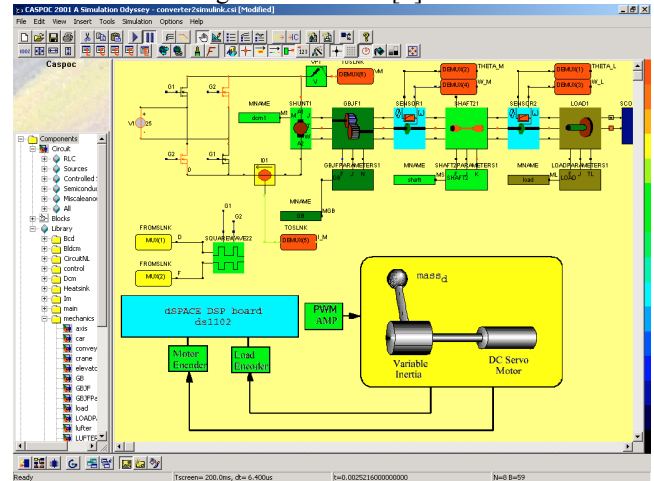

Figure 20: Motion Control System with Power converter, DC machine and two-mass mechanical load

Design of electrical machines in Tesla, where a model of the machine prototype is coupled with the circuit simulator is presented in [3].
Optimization of the entire drive system can be hereby performed. The electromechanical characteristics are obtained using the RAD tool and enable the designer to optimize the design in a short time and very cost efficient.

Important phase in the design is the realization of the control. Embedded control is in Power Electronic systems and electrical drives still more and more replacing the traditional electronic control [6]. The design of embedded controls usually takes place in a development environment programming the microprocessor, micro controller or DSP. Important in the design of embedded controls is the interaction with the controllable power electronics Fig.21.
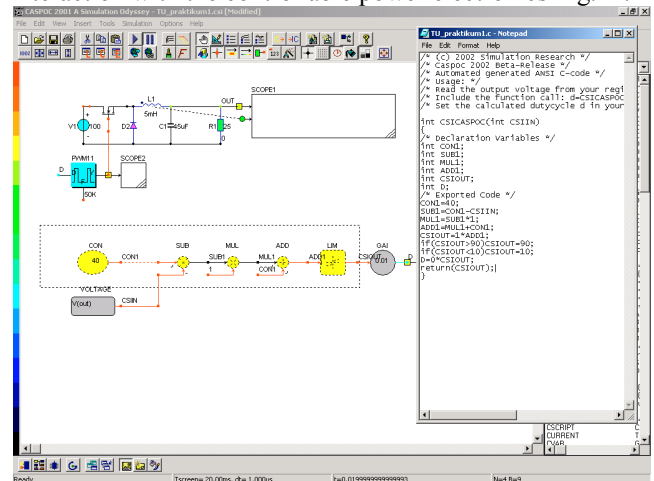

Figure 21; Debugging control source code during the simulation

Therefore a combination between the program development environment and the Power Electronics simulator is required. Further generation of the embedded C/C++ code automatically from the simulation blocks speeds up design.

4. Conclusion

As power electronic and drive systems are getting more complex today, the simulation / animation used for education is requiring more features. Two main directions in the development of simulation / animation tools are discussed in this paper. First the integrated simulation approach is important because of the multidisciplinary and compact integration of systems. Second, for education the animation features are important in order to understand the working principles of the system and to have the possibility to "Freeze and Go Back" feature with the animation.

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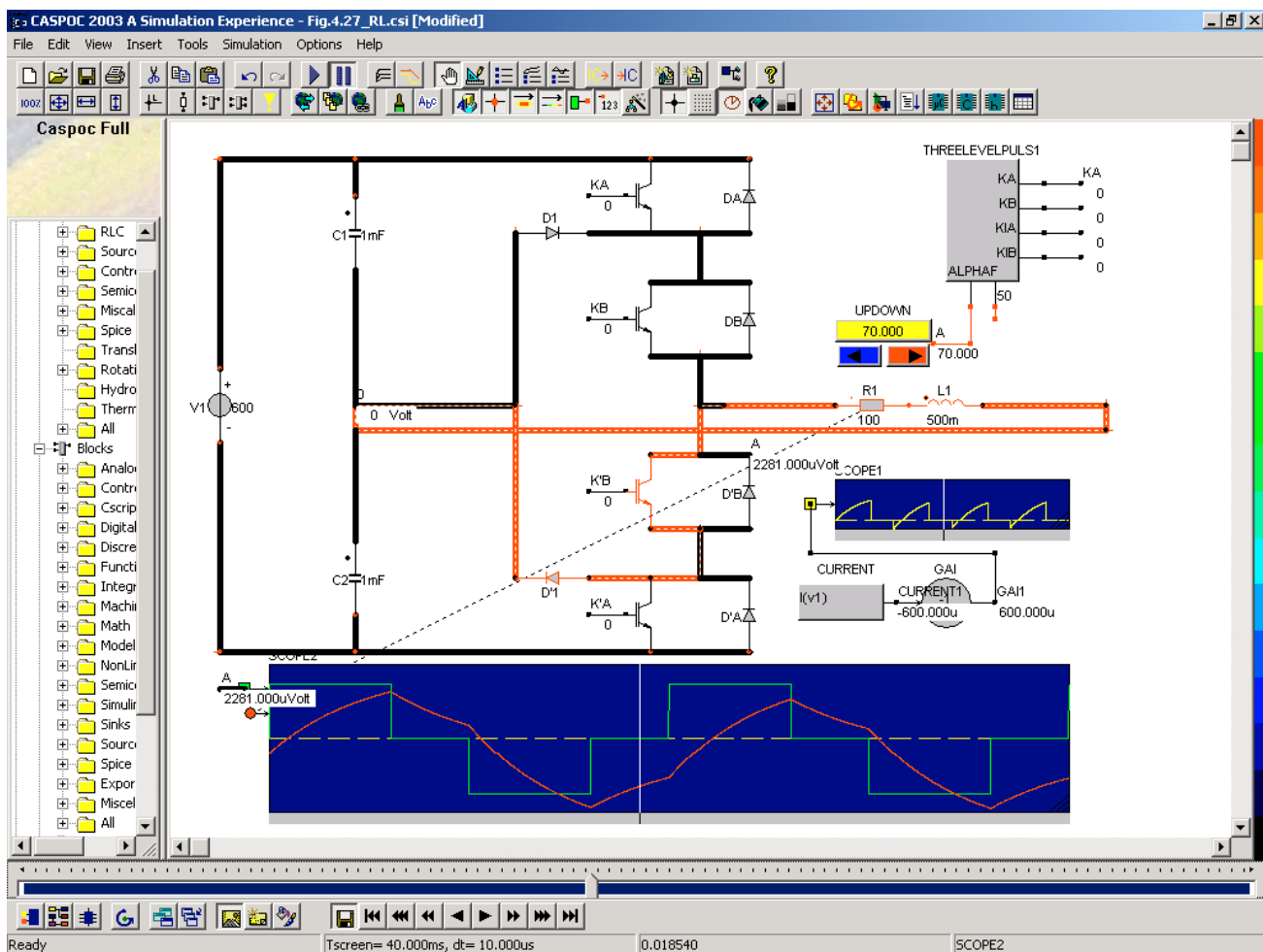
Figure 22: Three level converter, using the "Freeze and Go Back" feature the student can see the switching of the topology and the thereby associated current path. By moving the track-bar, each point in time can be analyzed and moving the track-bar draws the correct current path in the schematic.