

Integrated Control - Simulation Design Approach

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Abstract: In this paper the modeling of motion control system with Variable Structure System (VSS) theory using Matlab/Simulink and Caspoc is elaborated. The control is modeled in Simulink, while the power converter is modeled in Caspoc. This has advantages on both sides. Powerful toolboxes existing for Simulink can be used and the power electronics can be modeled in detail in the dedicated power electronics and drives simulation program Caspoc. This approach and advantages of it are demonstrated on the motion control system. Experimental results of a DSP-controlled single-degree-of- freedom motion-control system are presented too and compared with the simulation.

1. Introduction

Modern design of a power electronics system is often verified by simulation. There are several circuit simulation packages in use and each of them has some strong and some weak features. The circuit simulation itself is not satisfactory any more without proper system analysis and design. Understanding the strength of different CAD tools and integrating them

in the design process allows investigating more design aspects than only circuit simulation.

Typical power electronics system analyses consist of many aspects. 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 1. A power electronics simulator is central in this case (used simulator Caspoc). The interaction and data exchange with different analysis and design tools is hereby necessary.

As an example the interchange with Ansys is shown where for a SRM drive the inductance is calculated depending on the position of the rotor. About the coupling of the network simulator (Caspoc) with Finite element analysis package (Ansys) is reported in [8] and with IES in [9].

Another example is the thermal effects. The different temperature of the elements results in different circuit

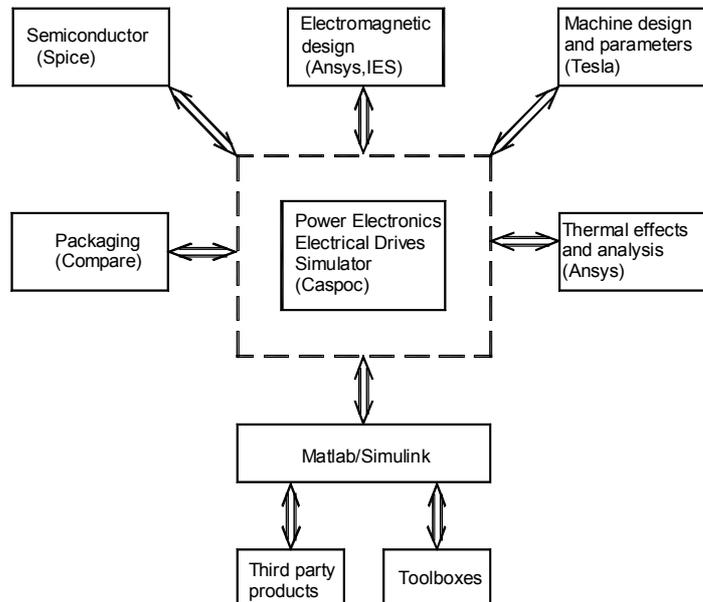


Figure 1 Integrated simulation approach

parameters, especially for the on-resistance of a Power Mosfet [7].

Design of electrical machines in Tesla, where a model of the machine prototype is coupled with the circuit simulator is presented in another reference [6].

One of the strong features of Matlab/Simulink are the toolboxes such as the Control toolbox with detailed description of several control methods. In this paper the advantages of modeling the control in Matlab/Simulink will be connected with the circuit simulator. The co-simulation between Matlab/Simulink and the circuit simulator Caspoc 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.

First an overview of the coupled simulation is given and second the theoretical background of the system with VSS and sliding mode controller is revealed. The theory is applied to a motion control system and simulation and practical experience is shown.

2. Need for Simulation in controller design

To understand the advantages of a combined simulation the strengths of the various existing programs have to be emphasized. Where Simulink is thanks to the various toolboxes good in modelling and simulation of the control systems, it lacks support for power electronics simulation. Also the recently developed Power Systems toolbox didn't meet the

goals many power electronics engineers have in mind. It lacks especially the component models, speed and accuracy of the simulation. Due to the numerical integration method and network calculation method used, the power toolbox suffers from the algebraic loop. It requires that a parasitic inductance and or capacitance be added to the circuit, which increases the order of the system.

On the other side Caspoc was developed dedicated to the simulation and animation of power electronics and electrical drives. It is therefore much better suited for the simulation of switching circuits with highly non-linear switching models. However it is possible to combine both simulations through the open interfaces in both Simulink and Caspoc and such an approach is demonstrated in this paper. Combination of both simulation packages seems to be advantageous for educational purpose too. Students are on one side familiar with the Simulink from the basic curricula. Caspoc is very easy to handle and learn in a short time.

In Figure 2 the coupling Simulink – Caspoc is depicted. In Matlab, a matlab mathematical script is used to calculate parameters for the VSS. In Simulink, the block Caspoc2Simulink calls via a S-function the circuit simulator Caspoc at each time step. After one simulation time-step in Caspoc, the in Caspoc calculated detailed currents, voltages and/or other variables such as speed, torque or position, these are supplied back to the Simulink.

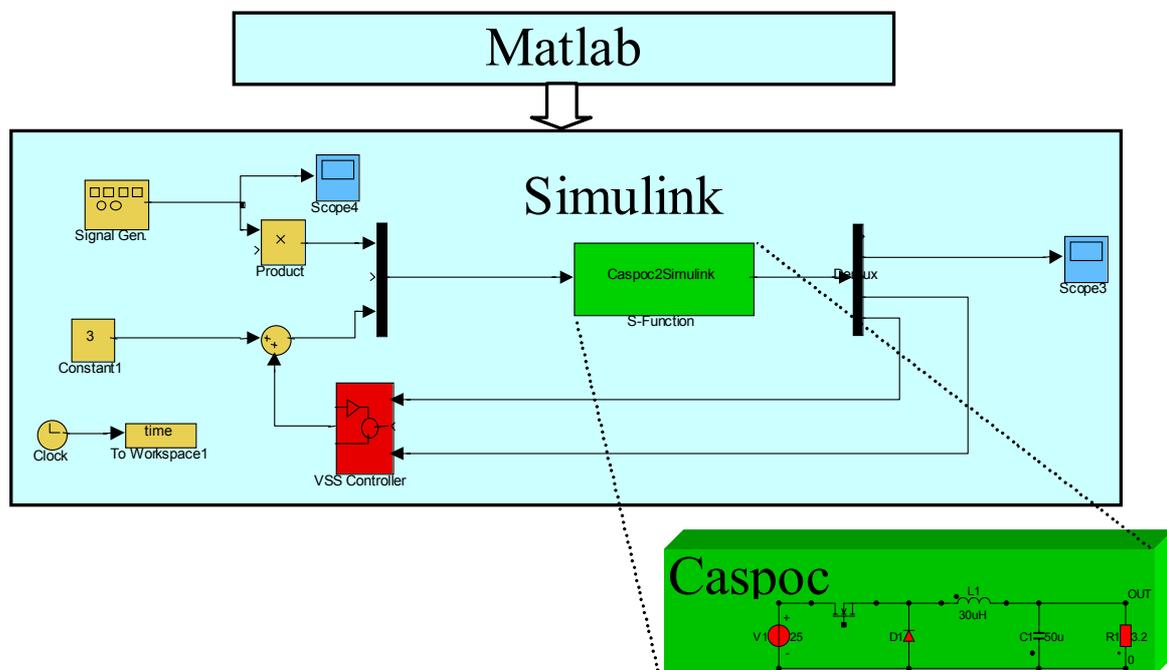


Figure 2 Coupling between Matlab/Simulink and Caspoc

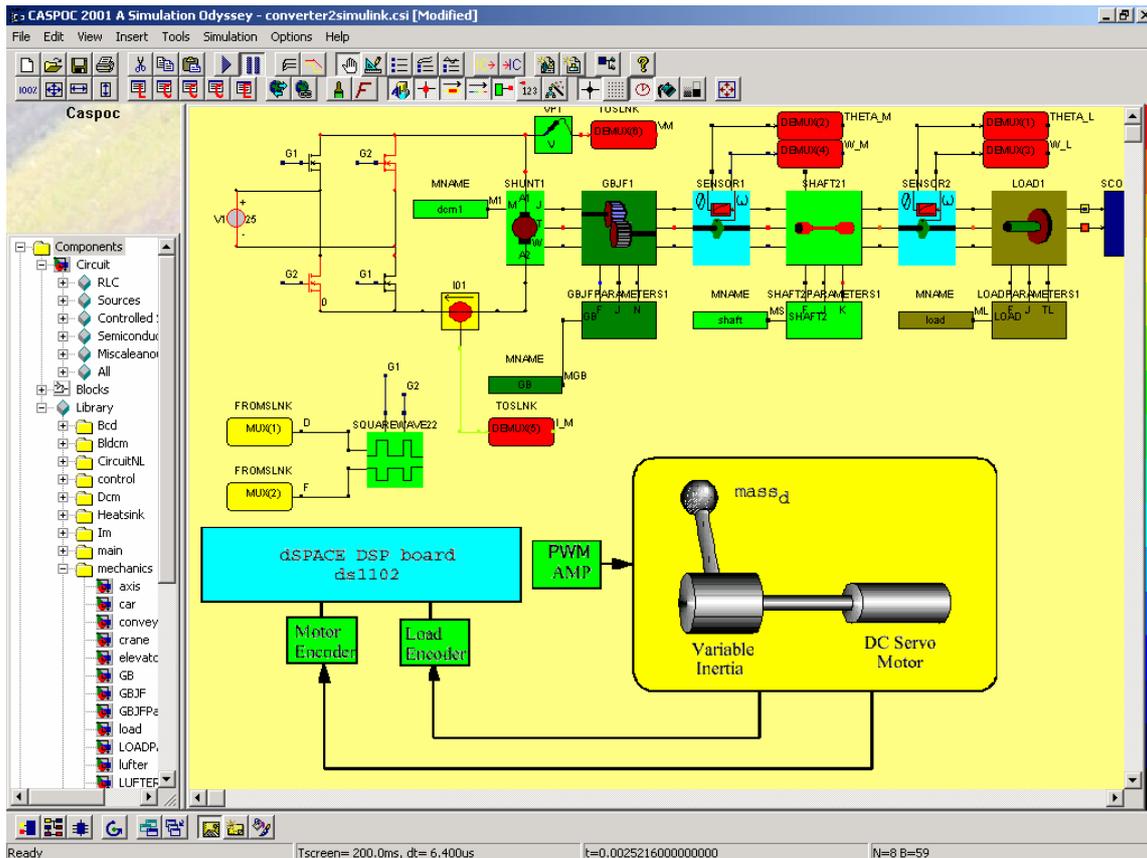


Figure 3 Motion Control System with Power converter, DC machine and two-mass mechanical load.

At the start of the investigation several Caspoc models were ready and the control was already simulated with Simulink. In the first iteration an averaged model of the system in Simulink was used. Combination of both tools was the easiest and most advantageous step to do and in the second step Caspoc contains the detailed switching system.

3. Implementation

In Figure 3 the power electronics circuit with electrical DC machine and mechanical load is modeled. The inverter is modeled in detail containing models for the used mosfets. The output of the inverter is connected to the DC machine, which in this case is a simple shunt machine. The DC machine is connected to the drive train consisting of a gearbox, flexible shaft and rotating load. Position and speed of the total drive is measured on both sides of the flexible shaft. Parameters for the components come from a Caspoc database, so only the types of

mechanical components have to be defined. The control of the mosfets is done using a control block for which the switching frequency and the duty cycle are provided by the control in Simulink. The measured DC link voltage machine current as well as the speed and position of the drive train are exported to Simulink using the ToSlmk blocks. The control variables from Simulink are imported using the FromSlmk blocks. The freedom to define and model the power electronics circuit, its connection to electrical machines and mechanical drive trains are the clear advantages of a program like Caspoc. After creating the model in Caspoc, one can continue to develop the control in Simulink.

In Figure 4 the model for Simulink is displayed. In this model the Variable Structure System (VSS) is modeled twice. First (black/white) completely in Simulink and second (colored) as a combined Simulink/Caspoc model. The results are displayed in the same scopes for comparison.

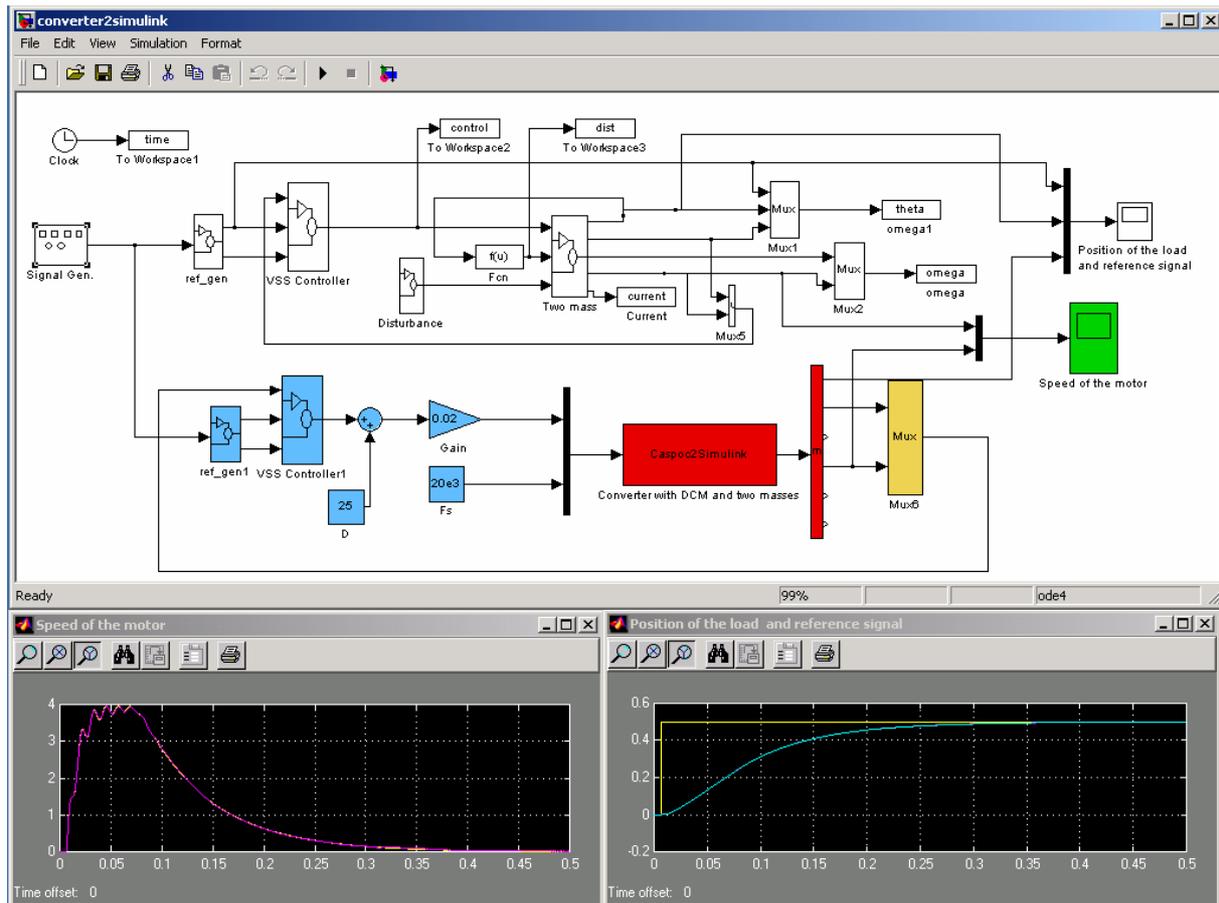


Figure 4 Simulink model of a Variable structure system example and simulation results

In the first model in Simulink an averaged modeled is used to mimic the power converter. In the second model the complete power converter with mosfets is modeled on the circuit level. The Caspoc2Simulink block represents the model of the power converter with electrical machine and drive train in Caspoc. Mux and Demux blocks are used for the communication between Caspoc and Simulink. The control signal from the Simulink model is fed into the ref_gen1 and VSS_Controller1 blocks. The control signal from the VSS controller is then scaled to the duty cycle [0..1] which is fed to Caspoc. The switching frequency of 20kHz is constant. The results from the Simulink block (Two Mass) and the results from the Caspoc model (Converter with CDM and two masses) are displayed in the scopes on the bottom of the Figure 4. The scope on the left shows the speed of the machine, while the scope on the right side shows the position of the load. For both models the speed shows a small oscillation caused by the flexible coupling between the machine and the load. The same oscillation can be seen in the experimental results (see the phase trajectory, when it reaches the sliding line in

Figure 6). It demonstrates that the integrated Simulink-Caspoc simulation presents more realistic result than a Simulink average model simulation.

4. Simulation Results

The simulation results from the combined simulation are presented using the *plot* command from Matlab. In Figure 4 the results are presented for 0.5 seconds.

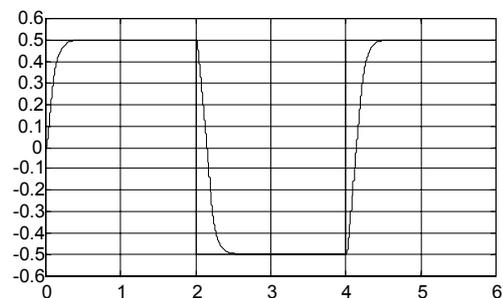


Figure 5 Position and reference as function of time

Here the scopes in Simulink are used for presenting the simulation results. For the simulation of 6 seconds, the results are written to the Matlab workspace and displayed in figure 6, 7, 8 and 9. Figure 6 shows the speed and reference signal of the load. From the results it is clear that there are no more oscillations when the VSS control is applied.

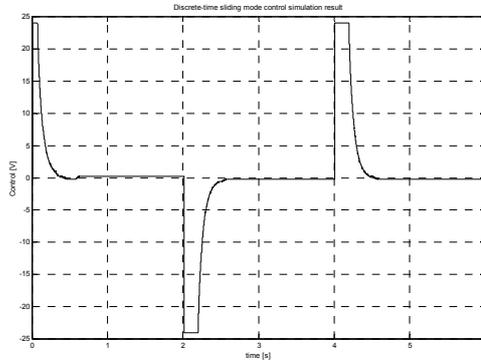


Figure 6 Control [V]

Figure 7 shows the current through the DC machine as calculated in Caspoc

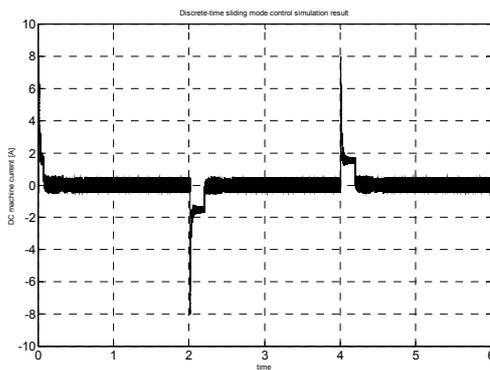


Figure 7 DC machine current [A]

Figure 8 shows the speed of the load. Observe the small oscillations caused by the flexible shaft.

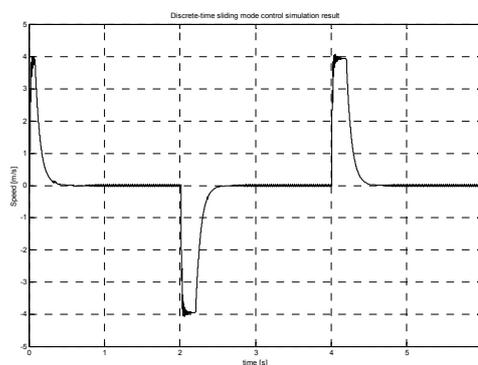


Figure 8 Speed [rad/s]

Figure 9 shows the torque on the flexible axis. The switching process in the inverter causes the torque ripple.

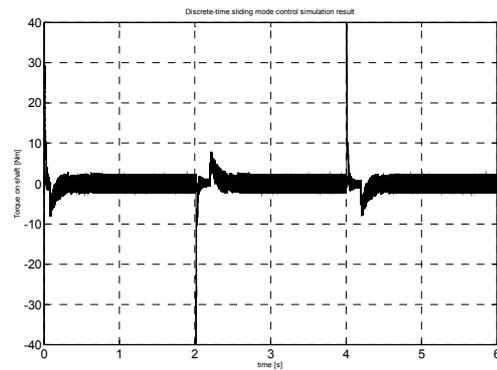


Figure 9 Torque on Shaft [Nm]

5. Experimental results

The experimental system consists of a conventional DC servo gear motor with encoder feedback and variable inertia load coupled by a relatively rigid shaft, as shown in Figure 1. The controller is implemented using a DSP as the computation engine. Chopper switching frequency was more than ten times higher than the controller sampling frequency. $T_{sampling}=1000\mu s$ $T_{chopper}=50\mu s$. Since a second-order model is applied, the sliding "surface" is a sliding line that can be described by a constant K in (3). In this case, K is scalar. The motion along the sliding line can be described by one time constant,

$$T=1/K=1/15 \text{ s}$$

The experimental results are shown in Figure 10,11 and 12. The reference was a pulse train. In the Figure 10 the time functions of the reference and the angular position of the load, in Figure 11 the phase trajectory, and in Figure 12 the control action are shown.

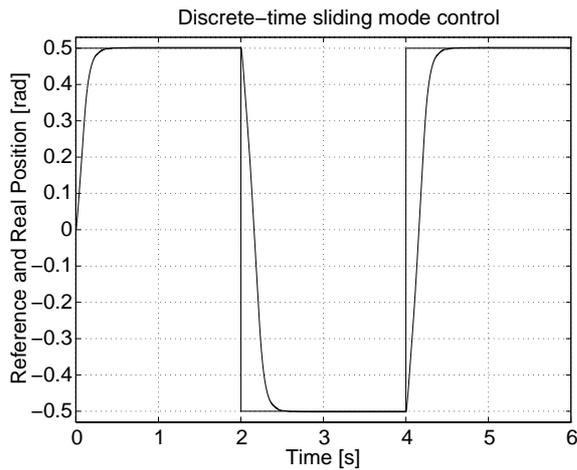


Figure 10 Experimental result

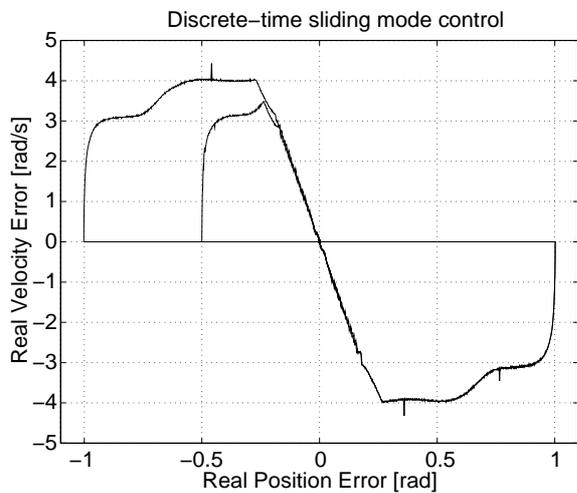


Figure 11 Experimental results

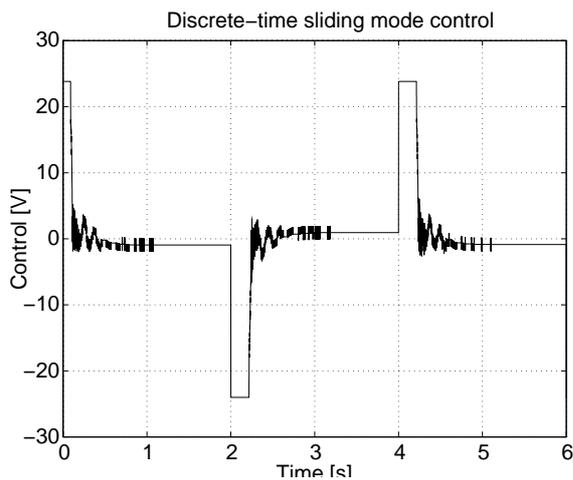


Figure 12 Experimental results

6. Conclusion

This paper discusses integrated simulation of a motion control system with VSS control. It demonstrates that the use of two different packages can be advantageous and lead to a complex system simulation with a sophisticated control. Theoretical results are confirmed with the practical experience.

References

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