

ANALYSIS, MODELING AND CONTROL OF POWER ELECTRONIC SYSTEMS AND THEIR SIMULATION AS AN EDUCATIONAL SUPPORT

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Abstract

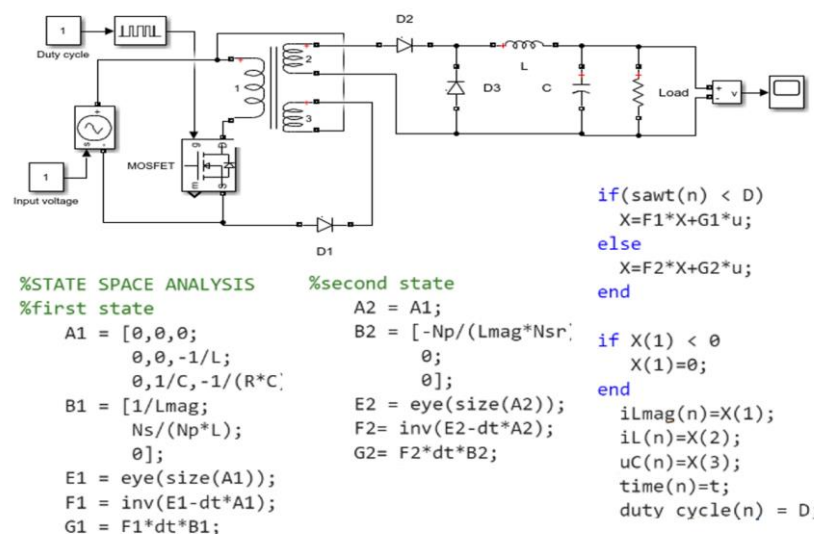
Power semiconductor devices are frequently used in contemporary world. They are used in all areas of everyday life and industrial applications. Thanks to this fact, it is necessary for current and new professionals to be trained and educated in the given theory. Part of this theory, in which our students are educated is the state space analysis of power systems, which represents their mathematical descriptions. Therefore, we created multiple simulation models of many power electronic systems. These models are used by students to verify the correctness of the performed state space analysis of the systems and to compare their results with classical circuit wiring diagram. The aim of such a simulation models is to introduce students to the variety of possibilities to analyze power electronic systems, understanding of their functionality, and also their open loop or closed loop control. There are also other benefits, like deeper understanding of mathematical skills. This paper describes multiple simulation models (topologies) of power systems, their analysis and control.

Keywords: Power electronics, simulation models, state space analysis, control systems.

1. Introduction

The power electronic is one of the youngest field of electrotechnical department. It is relatively new area in electrical engineering. Therefore, it is very important to be professionally educated in this topic. For our students it is necessary to understand how individual power semiconductor topologies work. This knowledge includes both theoretical description and its mathematical interpretation and of course simulation verification. The main point of this issue is to teach students to implement their knowledge not only in a schematic simulation area but also to improve their mathematical and programming skills and lead them to gain new experiences.

Figure 1. Simulink simulation compare to state space analysis in MATLAB script for isolated DC/DC Forward converter.



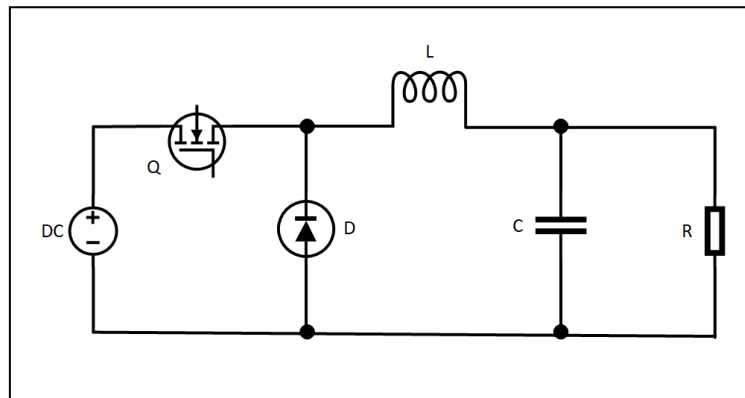
2. Programming skills improving education

In our case firstly it is necessary to mention how this programming skills are improving education. Here it is necessary to remember that individual simulation applications are preceded by a certain number of steps that require some degree of knowledge. In order to create a certain simulation model, it is necessary for students to use laws that are applied in electrical engineering for description of the electronic system to obtain a mathematical model. Then it must be modified using mathematical procedures to a shape that can be used in a given simulation model. As we can see, in this process, students will improve in both programming, mathematical and electrotechnical skills and knowledge.

3. The procedure for creating given simulation models of various power semiconductor devices

In this section we will take brief look to procedure by which our students are obtaining simulation models and thus improving their skills. We will show it on one of the most basic topologies used in the field of power electronics, specifically on the Buck converter.

Figure 2. Wiring diagram of the Buck converter (Barrenetxea, Baraia, Larrazabal, & Zubimendi, 2018).



3.1. Obtaining a mathematical description of the given electronic system

Firstly, it is necessary to analyze this system using basic electrotechnical laws such as Kirchoff's laws. By applying this laws, we get its description and by using a little modification we get it in the form of differential equations. Devices such as DC/DC converters operate in two operational states and therefore we get equations for each state (Jarabicová, & Kaščák, 2019).

State equations for the first mode of operation:

$$\begin{aligned}\frac{di_L}{dt} &= -\frac{1}{L}u_C + \frac{1}{L}u_{IN} \\ \frac{du_C}{dt} &= \frac{1}{C}i_L - \frac{1}{RC}u_C\end{aligned}$$

State equations for the second mode of operation:

$$\begin{aligned}\frac{di_L}{dt} &= -\frac{1}{L}u_C \\ \frac{du_C}{dt} &= \frac{1}{C}i_L - \frac{1}{RC}u_C \quad (\text{same as in the first mode})\end{aligned}$$

3.2. Conversion of differential equations to the matrix form and obtaining a state space model of the system

The second step is to obtain a mathematical description of the system in the matrix shape which is important for the simulation verification of the obtained results (Jarabicová, & Kaščák, 2019).

State space model for the first state:

$$\frac{d}{dt} \begin{pmatrix} i_L \\ u_C \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} \begin{pmatrix} i_L \\ u_C \end{pmatrix} + \begin{pmatrix} \frac{1}{L} & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} u_{IN} \\ 0 \end{pmatrix}$$

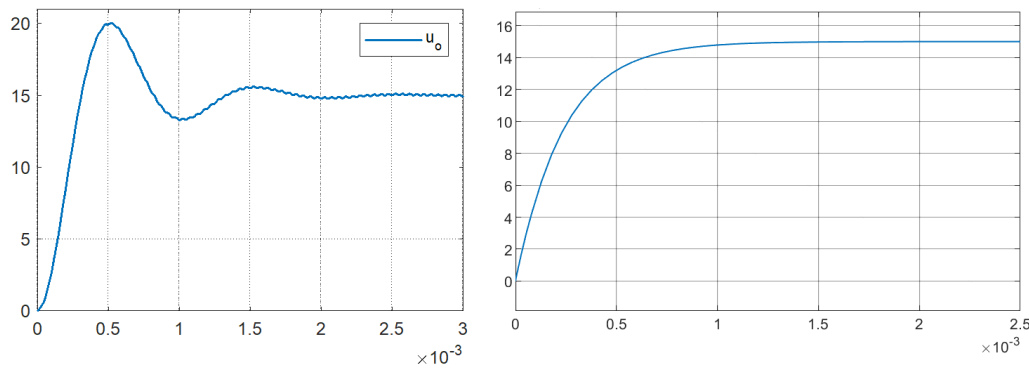
State space model for the second state:

$$\frac{d}{dt} \begin{pmatrix} i_L \\ u_C \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} \begin{pmatrix} i_L \\ u_C \end{pmatrix} + \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} u_{IN} \\ 0 \end{pmatrix}$$

3.3. Simulation verification in a chosen program

Last step of this analysis is to verify if our obtained results correspond to expectations. For this application we have chosen program named MATLAB. It is a program which allows the analysis of the system using such a mathematical model but also using a simple circuit diagram and therefore students can verify the correctness of their obtained mathematical descriptions (Jarabicová, & Kaščák, 2019).

Figure 3. The output voltage course for (a) MATLAB script simulation and (b) Simulink model simulation.



4. Conclusion

As we could see, the study and the field of power electronics also contributes to the improving of education of students. It teaches them to perceive the connections between different technical areas. In this case, it is area whether mathematical, theoretical, electrotechnical or programming. Our students have the opportunity to deeply improve this knowledge, because we do such applications with them on different types of electronic topologies. In many cases, there are also much more complicated analyses of systems, since for individual circuits it is possible to consider different parasitic properties of circuit elements. We apply it on topologies such as rectifiers, DC/DC converters, inverters and power semiconductor converters in general.

Acknowledgements

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