FUZZY LOGIC CONTROL FOR A DC TO DC BUCK CONVERTER

Jenica-Ileana CORCAU, Liviu DINCA

*University of Craiova, Faculty of Electrical Engineering,
Department of Electrical, Energetic and Aerospace Engineering, Craiova, Romania
(jcorcau@elth.ucv.ro, ldinca@elth.ucv.ro)

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Abstract: *In this paper one presents a model and an analysis of a dc-to-dc Buck converter, in closed loop, from 24V to 12 V with a power of 500 W. Model is implemented in MATLAB/SIMULINK toolbox SIMPOWERSYS. Control system is a fuzzy logic one, Mamdani type, and using P.I. configuration. One opted for a fuzzy controller due to its flexibility in its configuration and tuning process, and also because it doesn't need to know a mathematical model for the Buck converter. Fuzzy controller is composed of two sub-controllers in parallel, one for the proportional component and a second for integrative component. One proposes this configuration because fewer inference rules are necessary and also the tuning process is easily accomplished compared to a fuzzy controller with two inputs. Implemented model is validated by numerical simulations and the results are realistic and confirm the possibility to use this type of controller.*

Keywords: *dc to dc buck converter, fuzzy logic controller, analysis*

1. INTRODUCTION

In modern electric power systems, interface between power sources as fuel cells, photovoltaic cells, batteries, and the power bus, and also the control for the power bus voltage are realized by static DC to DC converters. These converters have a wide and continuous development with evolution of power electronic devices. There are many constructive variants with specific destinations as: aircraft, spaceships, telecommunications etc. On aircraft both DC and AC converters are used. In the most situations, input voltage - V_s, for converters is not stabilized, but converter produce a stabilized output voltage - V_{out}, with a different amplitude and possibly with a different polarity than V_s [1]-[2].

Conversion ratio, or voltage gain, in stationary regime $M(d)$ is defined as ratio between output DC voltage V_{out} and input DC voltage V_s [2]

$$M(d) = \frac{V_{out}}{V_s}. \tag{1}$$

so, for the buck converter

$$M(d) = d. \tag{2}$$

Command pulses duty-cycle is

$$d = \frac{t_{on}}{T_s}, \tag{3}$$

where T_S is the switching period.

A wide used method for duty cycle variation is PWM modulation of the command signal of the switching device. The switch is ON when the command signal is ‘1’ and is OFF when the command signal is ‘0’. PWM generator produce pulses with a specified frequency, e.g. 10 kHz, in this case rectangle pulses, with values ‘1’ and ‘0’. Input signal for PWM changes between -1 and 1, and duty cycle, of the output pulses, changes between 1 and 0 respectively [3]-[10].

Figure 1 presents DC to DC buck converter in closed loop with a fuzzy logic controller. In figure 2 one presents an equivalent circuit for continuous current regime (CCM) of the buck converter.

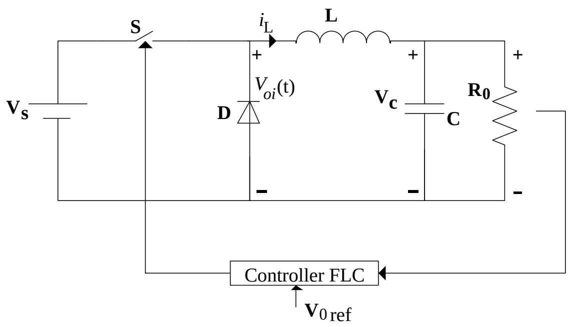


FIG. 1. DC to DC buck converter in closed loop

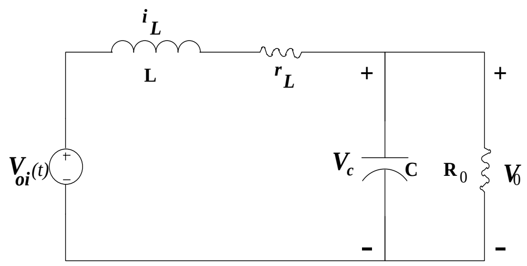


FIG. 2. An equivalent circuit for CCM regime of the buck converter.

Applying Kirchhoff laws for the circuit in figure 2 one obtain the following equations [6]

$$\begin{aligned} & r_L i_L + L\frac{\mathrm{d}i_L}{\mathrm{d}t} + V_C = V_{0i} \\ & i_L - C\frac{\mathrm{d}V_C}{\mathrm{d}t} - \frac{V_C}{R} = 0 \end{aligned} . \tag{4}$$

Automatic control of buck converters was studied in many works, like [3]-[10]. One follows to stabilize output voltage with respect input voltage variations and eventually with respect the converter’s load. For Buck converter, static theoretic characteristic is

$$U_{out} = U_{in} \cdot d, \tag{5}$$

where d is the duty cycle of the command rectangular signal of the switch. It can vary between 0 and 1 and one observes the output voltage is less than the input.

Classical control like P., P.I., P.D. and P.I.D. need to know a linear mathematical model for the converter.

A modern control technique that doesn't need to know a mathematical model for the converter is fuzzy logic technique. One can to obtain P., P.I., P.D. and P.I.D. fuzzy controllers

2. FUZZY CONTROLLER FOR DC TO DC BUCK CONVERTER

Fuzzy controllers fulfill the same tasks like a classic P.I.D. controller. Fuzzy controller differs from the classic one in that it manages the control complex space in a heuristic manner. However, the fuzzy controller can approximate, with any precision level, linear and non-linear control functions. In many situations is easier to obtain a fuzzy controller with high performance than a classic P.I.D. controller with same performances [11].

Implementation of a fuzzy controller implies control function codification in fuzzy rules set which operates on fuzzy sets resulted in the fuzzyfication of the input and output domains.

Usually, a P.I. fuzzy controller has two inputs and one output. Fuzzy controller in this application consists in two fuzzy sub-controllers (with one input and one output), one for the proportional component and one the second for the integral component. One choose this option due to simplified definition of the inference rules and an easier tuning process. Along side these advantages, this configuration needs a shorter calculus time.

First fuzzy controller is P type with one input (output voltage error) and one output (duty cycle variation). There are 4 membership functions both for input and the output. These membership functions are presented in figures 3.a and 3.b .

Linguistic terms for input (output voltage error) were considered *NAe, NMe , PMe* and *PAe* and for output (duty cycle variation) *YNG, YNMS, YPMS, YPG.* Inference rules were defined as: *IF error is NAe THAN output is YNG; IF error is NMe THAN output is YNMS; IF error is PMe THAN output is YPMS; IF error is PAe THAN output is YPG.* By this way results control function in figure 3.c.

Fuzzy controller for the integrative component considered also 4 membership functions for input and for output. Membership functions were considered trapezoidal, like in figures 3.d and 3.e.

Linguistic terms for the input (output voltage integral) were considered *NAie, NMie , PMie* and *PAie* and for output (duty cycle variation) *YNG, YNMS, YPMS, YPG.* Inference rules were defined as: *IF error is NAie THAN output is YNG; IF error is NMie THAN output is YNMS; IF error is PMie THAN output is YPMS; IF error is PAie THAN output is YPG.* By this way results control function in figure 3.f. Closed loop converter system was implemented in SIMULINK in figure 4. This kind of fuzzy controller was propose by authors in [7].

In the definition of membership functions and inference rules one aimed to obtain a higher slope for the control surface near origin, both for proportional and integrative component. This fact can be observed for the control surfaces in figures 3.c and 3.f.

3. NUMERICAL SIMULATIONS

For a converter with the following parameters - input voltage 24 V, output voltage 12 V, inductance 56.5 μH and capacity 166.7 μF, switching frequency 10 kHz and load resistance 5 Ω), were performed simulations in SIMULINK, using the fuzzy controller above. As test signals, one used first an input voltage step from 24 V to 27 V, and then a load step from 10 Ω to 5 Ω. Numerical simulations results are shown in figure 5. For the fuzzy controller, in simulations, a refresh rate of 1 kHz was used.

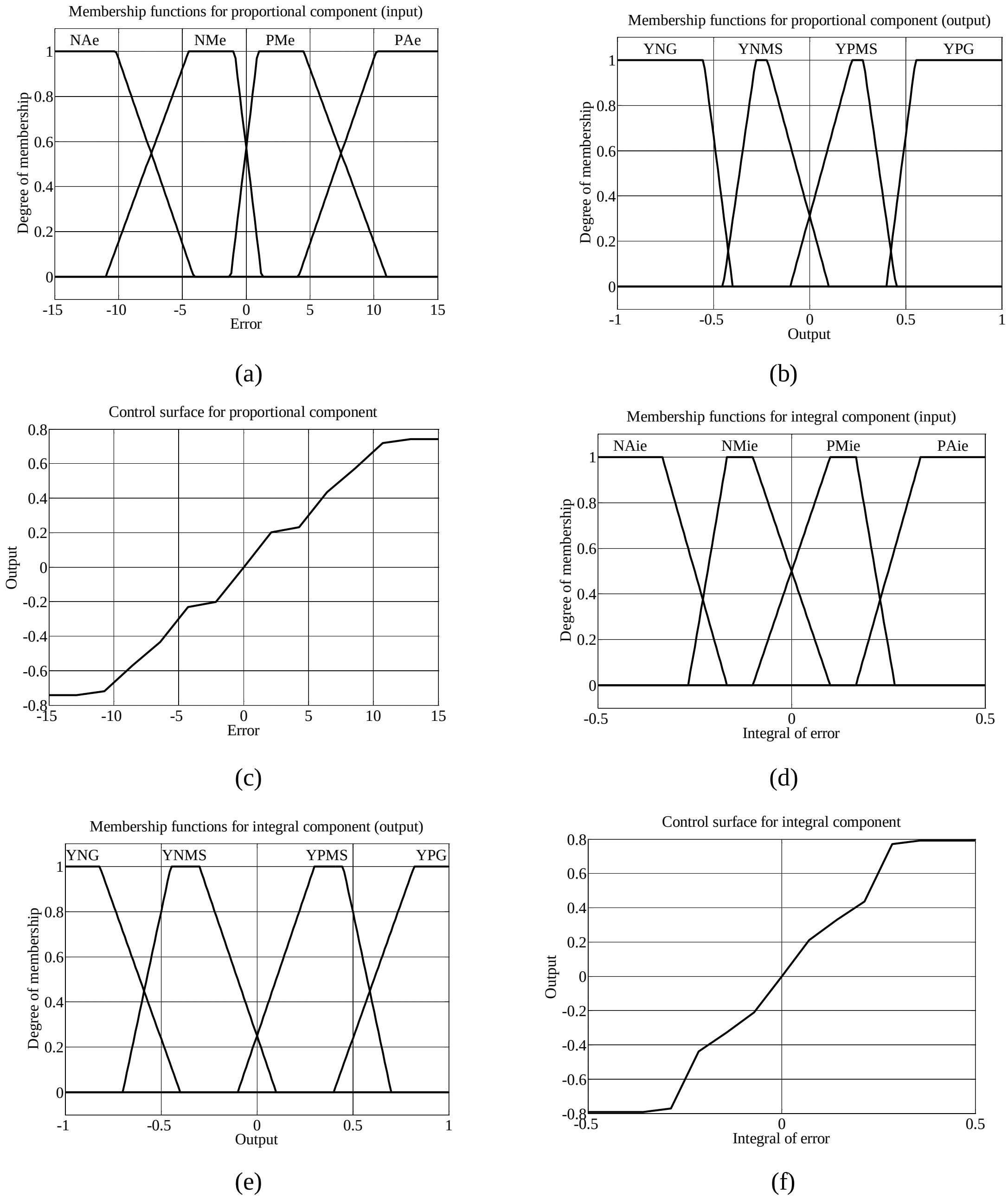


FIG. 3. Fuzzy controller for proportional component and for integrative component

Taking into account the very small variations of the output voltage, one can say this controller can be used for applications that need good output voltage stabilization.

An interesting remark is the presence of some random ripple which is not the simple effect of the switching process but of the interference between the controller and switching process. This ripple decreases with the output current. One can obtain a better behavior of the converter by switching pulses increasing and concurrent improving of the gain and time constant of the fuzzy controller.

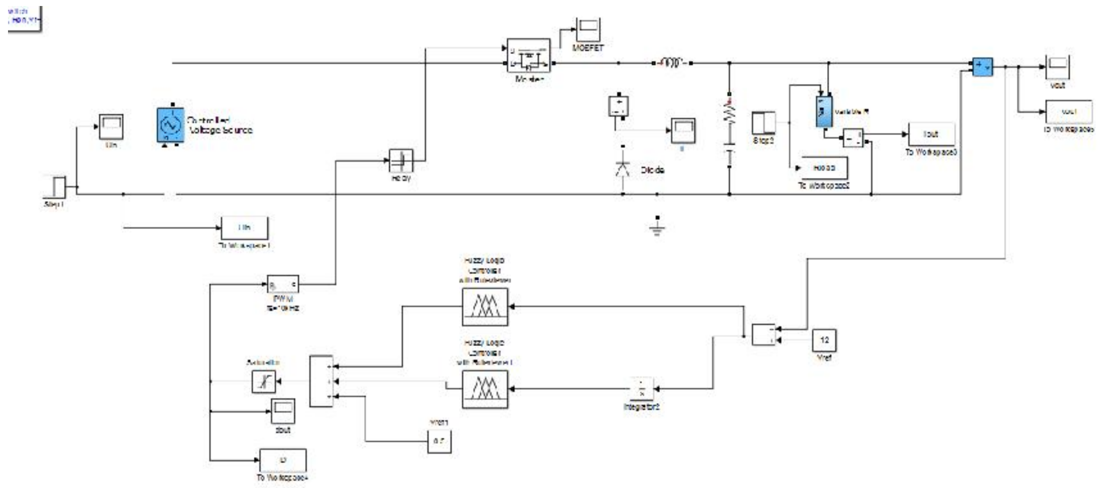
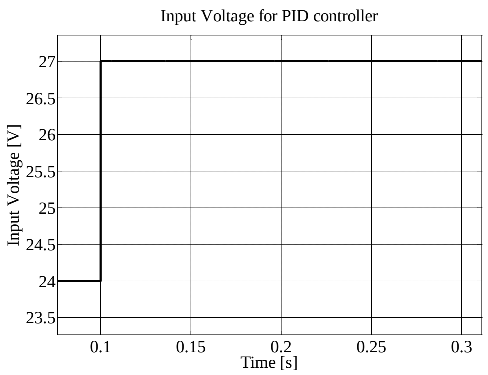
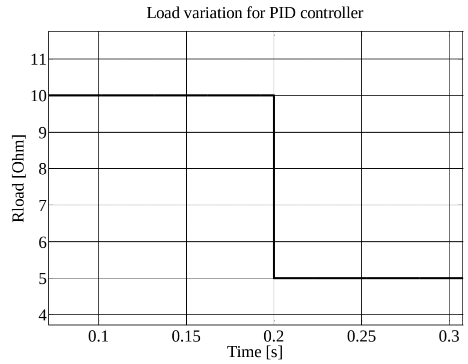


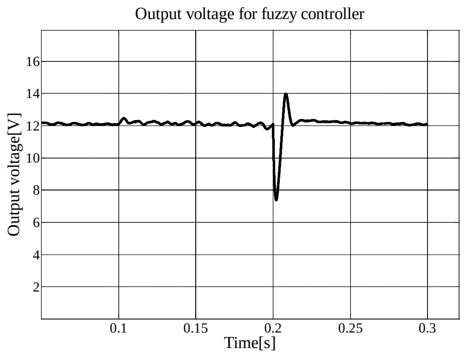
FIG. 4. Matlab/Simulink model for dc to dc buck converter in closed loop



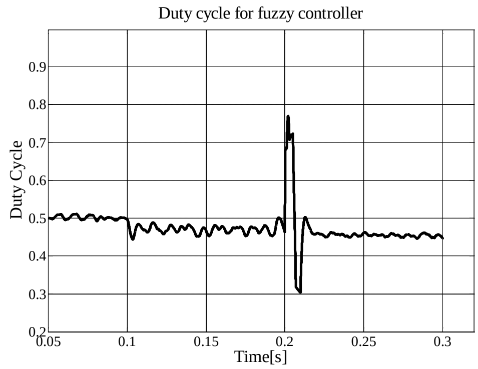
(a)



(b)



(c)



(d)

FIG. 5. Behavior of the converter with fuzzy controller

CONCLUSIONS

This paper presents modeling and analysis of a DC to DC buck converter (with a gain lesser one) by numerical simulation. Closed loop model was implemented in MATLAB/SIMULINK toolbox SIMPOWERSYS, and the controller is fuzzy type. This kind of controller was proposed by authors in [7] for a DC-to-DC boost converter. Good behavior of the Buck converter studied in this paper proves the robustness of the fuzzy controllers. Fuzzy controller shows good stabilization qualities while it doesn't needs to know the mathematical model of the Buck converter in the controller design process. Simplified version with two more simple controllers in parallel, one for the proportional component and one for the integrative component allows simplifying the inference rules definition and the controller tuning. Moreover, the calculus time for this configuration is shorter than the calculus time for a controller with two inputs and one output, due to a smaller calculus volume.

REFERENCES

[1] M. H. Rashid, *Power Electronics Circuits, Devices, And Applications*, 3rd edition, University of West Florida, Pearson Prentice Hall, 2003;

[2] R. W. Erickson and D. Maksimovic, *Fundamentals of Power Electronics*, Second Edition. 912 pp., ISBN 0-7923-7270-0;

[3] G. Feng, W. Zhang, and Yan-Fei Liu, *An adaptive current mode fuzzy logic controller for dc-to-dc converters*, IEEE 2003, page 983-989;

[4] P. Mattavelli, L. Rossetto, G. Spiazzi and P. Tenti, *General-purpose fuzzy controller for dc/dc converters*, APEC, 1995;

[5] A. G. Perry, G. Feng, Yan-Fei Liu and P.C. Sen, *A New Design Method for PI-like Fuzzy Logic Controllers for DC-to-DC Converters*, 2004 35th Annual IEEE Power Electronics Specialists Conference, pp. 3751-3757;

[6] S. Yigang, *Performance Improvement of dc-dc converters using fuzzy logic control (FLC).* Master of Science Engineering, Ontario Canada, 1999;

[7] L. Dinca and J.I. Corcau, *P.I. Versus Fuzzy Control for a dc to dc boost converter*, SPEEDAM 2016, Paper submitted for publication;

[8] M. Salimi and A. Zakipour, *Direct Voltage Regulation of DC-DC Buck Converter in a Wide Range of Operation using Adaptive Input-Output Linearization*. IEEJ Transactions on Electrical and electronic Engineering,Vol. 10, Iss. 1, pp. 85-91, January 2015, ISSN 1931-4973.

[9] M Sahoo and S. Kumar, *High Gain Step-Up DC –DC Converter For DC Micro-Grid Application.* International Conference on Information and Automation for Sustainability, 2014, ISBN 978-1-4799-4598-6/14;

[10] Monzer Al Sakka, Joeri Van Mierlo and Hamid Gualous (2011). *DC/DC Converters for Electric Vehicles, Electric Vehicles - Modelling and Simulations,* Dr. Seref Soylu (Ed.), ISBN: 978-953-307-477-1, InTech, Available from: http://www.intechopen.com/books/electric-vehicles-modelling-and-simulations/dc-dcconverters- for-electric-vehicles;

[11] Eremia M., Cartina G., Petrica D., s.a. *Artificial intelligence techniques in the management of power systems*. Editura Agir, Bucuresti, 2006.