FUZZY REASONING ON BUCK DC-DC POWER CONVERTER PARAMETERS

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Abstract: The paper concerns power converter parameter analysis. Authors' software is implemented, and Matlab applications are used. The proposed approach, based on fuzzy production rules too, compares results in order last ones to be verified as a proper tool in parameter estimations on power devices. The presented technique is useful on power circuit parameters and controller characteristics and design.

Key words: fuzzy production rules, power converters, software, power circuits, controllers.

1. INTRODUCTION

Power electronics as an interdisciplinary field provides good opportunities for applying artificial intelligence techniques to the design and prototyping of power electronic devices and systems. The development of modern information and communication technologies, as well as computational mathematics and mathematical software, helps to stimulate this process [1-4]. In this regard, a process of development of the classic methods for designing power electronic devices and systems is observed in a direction of their automation and formalization through various innovative approaches. The fuzzy production rules are widely used in power converter control. However, such rules are rarely used in power device parameter estimations. The presented approach is based on [5, 6] in order elements of fuzzy set theory (including fuzzy numbers, their cores and supports handling) to be applied in a proper way. The authors' software, which is presented in [7-9], implements modeling and simulation of power systems; the proposed buck DC-DC converter is used as an example in the present paper too. A source code is developed in order fuzzy values to be used in inference processes (see [9]).

2. REASONING WITH FUZZY PRODUCTION RULES

The most popular fuzzy production rules have form

$$\text{IF } U_1 \text{ is } A_1 \text{ AND } U_2 \text{ is } A_2 \text{ AND} \ldots \text{ AND } U_n \text{ is } A_n \text{ THEN } V \text{ is } B \qquad (1)$$

where $U_1, U_2, \ldots, U_n, V$ are variables which take their values in base sets denoted by $X_1, X_2, \ldots, X_n, Y$ respectively, and $A_1, A_2, \ldots, A_n, B$ are fuzzy subsets of these sets [5, 6]. An extension of (1) is

$$\text{IF } U_1 \text{ is } A_1 \text{ AND } U_2 \text{ is } A_2 \text{ AND} \ldots \text{ AND } U_n \text{ is } A_n \text{ THEN } V \text{ is } B \ (\mu), \qquad (2)$$

where μ is a certainty degree of the rule.

Let $A_1', A_2', \ldots, A_n', B'$ be fuzzy sets in $X_1, X_2, \ldots, X_n, Y$ respectively, and let facts

$$U_1 \text{ is } A_1', \ U_2 \text{ is } A_2', \ \ldots, \ U_n \text{ is } A_n' \qquad (3)$$

be given. The following inference based on (1) and (3) can be considered:

$$\begin{array}{c} U_1 \text{ is } A_1', \ U_2 \text{ is } A_2', \ \ldots, \ U_n \text{ is } A_n' \\ \text{IF } U_1 \text{ is } A_1 \text{ AND } U_2 \text{ is } A_2 \text{ AND} \ldots \text{ AND } U_n \text{ is } A_n \text{ THEN } V \text{ is } B \\ \hline V \text{ is } B', \end{array} \qquad (4)$$

where the fuzzy value B' is defined by

$$\begin{aligned} B'(y) &= \mathrm{S}_{i \in \{1, 2, \ldots, n\}} B_i'(y), \quad y \in Y, \\ B_i'(y) &= \sup_{x_i \in X_i} \left[A_i'(x_i) \ \mathrm{T} \ F_{A_i \to B}(x_i, y) \right], \\ F_{A_i \to B} &: \ X_i \times Y \to [0, 1]. \end{aligned} \qquad (5)$$

$F_{A_i \to B}$ is a fuzzy relation, T is a T-norm, and S is a S-norm; in the present paper, the relation satisfies formula

$$B_i'(y) = \sup_{x_i \in X_i} \left[A_i'(x_i) \ \mathrm{T} \ F_{A_i \to B}(x_i, y) \right], \qquad (6)$$

and the T-norm being used is the minimum operator.

Example 1: A fuzzy production rule with one variable in its antecedent

Let features are defined in $Z = \{1, 2, 3, 4, 5\}$ by linguistic values in the following manner:

Table 1. Fuzzy values

Value	***Membership***				
	1	**2**	**3**	**4**	**5**
very low	1.0	0.6	0.0	0.0	0.0
low	1.0	0.8	0.1	0.0	0.0
more or less low	1.0	1.0	0.3	0.0	0.0
medium	0.0	0.5	1.0	0.5	0.0
more or less high	0.0	0.0	0.3	1.0	1.0
high	0.0	0.0	0.1	0.8	1.0
very high	0.0	0.0	0.0	0.6	1.0

Let the rule

$$\text{IF } K \text{ is } \textit{high} \text{ THEN } P \text{ is } \textit{medium}, \tag{7}$$

holds, and let the following fact is given:

$$K \text{ is } \textit{more or less high}. \tag{8}$$

According to (6):

$$F_{high \to medium}(x, y) = 1 \ \mathrm{T} \ [1 - high(x) + medium(y)]. \tag{9}$$

This relation can be represented by

$$F^{high \to medium} = \begin{Vmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 0.9 & 1 & 1 & 1 & 0.9 \\ 0.2 & 0.7 & 1 & 0.7 & 0.2 \\ 0 & 0.5 & 1 & 0.5 & 0 \end{Vmatrix}, \tag{10}$$

where $f_{x,y}^{high \to medium}$, $x, y \in Z$, satisfies

$$f_{x,y}^{high \to medium} = F_{high \to medium}(x, y). \tag{11}$$

An inference based on (7 - 9) gives

$$P(y) = \sup_{x \in Z} \big[more\_or\_less\_high(x) \ \mathrm{T}$$

$$\mathrm{T} \ F_{high \to medium}(x, y) \big], \quad y \in Z. \tag{12}$$

The calculated membership values of P are given below:

$$P = \langle 0.3, \ 0.7, \ 1, \ 0.7, \ 0.3 \rangle. \tag{13}$$

Example 2: A fuzzy production rule with two variables in its antecedent

Let the following rule holds:

$$\text{IF } L \text{ is } \textit{very low} \text{ AND } M \text{ is } \textit{low} \text{ THEN } Q \text{ is } \textit{very high}. \tag{14}$$

The variables L, M and Q are defined in base set Z too. Let two facts be given:

$$L \text{ is } \textit{low}, \quad M \text{ is } \textit{very low}. \tag{15}$$

Relations $F_{very\ low \to very\ high}$ and $F_{low \to very\ high}$ can be represented by

$$F^{very\ low \to very\ high} = \begin{Vmatrix} 0 & 0 & 0 & 0.6 & 1 \\ 0.4 & 0.4 & 0.4 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{Vmatrix}; \tag{16}$$

$$F^{low \rightarrow very\ high} = \left\| \begin{matrix} 0 & 0 & 0 & 0.8 & 1 \\ 0.2 & 0.2 & 0.2 & 0.9 & 1 \\ 0.9 & 0.9 & 0.9 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{matrix} \right\| . \qquad (17)$$

Inferences based on (14) and (15) gives for each $y \in Z$

$$Q'(y) = \sup_{x \in Z} \left[low(x) \ \mathrm{T} \ F_{very\ low \rightarrow very\ high}(x, y) \right]; \qquad (18)$$

$$Q''(y) = \sup_{x \in Z} \left[very\_low(x) \ \mathrm{T} \ F_{low \rightarrow very\ high}(x, y) \right]. \qquad (19)$$

This approach is discussed in the previous example, and the respective results are

$$Q' = \langle 0.4,\ 0.4,\ 0.4,\ 0.8,\ 1 \rangle; \qquad (20)$$

$$Q'' = \langle 0.2,\ 0.2,\ 0.2,\ 0.6,\ 1 \rangle. \qquad (21)$$

The common value of Q is

$$Q = Q' \ \mathrm{S} \ Q'' = \langle 0.4,\ 0.4,\ 0.4,\ 0.8,\ 1 \rangle. \qquad (22)$$

3. RESULTS ON POWER CONVERTER PARAMETERS

A Buck DC-DC power converter with PID controller is described in [7, 8]. The following its parameters are used in the present paper (see [9] too):

$$\begin{gathered} \mathrm{E} = 24\ \mathrm{V} \pm 35\ \%\ ;\ \mathrm{Utar} = 10\ \mathrm{V}\ ; \\ \mathrm{R} = 1\ \Omega \pm 35\ \%\ ;\ \mathrm{L} = 20\ \mu\mathrm{F} \pm 35\ \%\ ;\ \mathrm{C} = 20\ \mu\mathrm{F} \pm 15\ \%\ ; \\ \mathrm{Kp} = 2 \pm 15\ \%\ . \end{gathered} \qquad (23)$$

E denotes an input voltage, $Utar$ – a target output voltage, R – an output resistance, L – an inductance, C – a capacitance, Kp and Ki – coefficients of a PI controller. Estimations of two output parameters are shown on Fig. 2, 4, 6. *URmax* is a maximal output voltage. *Delay* is a setup time on a step response, i.e. time after which the output voltage belongs to interval $[9.9,\ 10.1]$ $[\mathrm{V}]$. Possibility distributions use the following default degrees of membership to intervals:

$$\begin{gathered} \mathrm{I}_{\mathrm{Par},3} \equiv [\ 0.85\ \mathrm{Par},\ \ 0.95\ \mathrm{Par}\ ] :\ 0.5 \\ \mathrm{I}_{\mathrm{Par},4} \equiv [\ 0.95\ \mathrm{Par},\ \ 1.05\ \mathrm{Par}\ ] :\ 1{,}0 \\ \mathrm{I}_{\mathrm{Par},5} \equiv [\ 1.05\ \mathrm{Par},\ \ 1.15\ \mathrm{Par}\ ] :\ 0.5 \\ \mathrm{Par} \in \{\mathrm{E},\ \mathrm{R},\ \mathrm{L},\ \mathrm{C},\ \mathrm{Kp},\ \mathrm{Ki}\}\ . \end{gathered} \qquad (24)$$

The chosen tolerance is 15% (intervals with juxtaposed zero values are not taken into account).

$$\begin{gathered} \mathrm{I}_{\mathrm{Par},1} \equiv [\ 0.65\ \mathrm{Par},\ \ 0.75\ \mathrm{Par}\ ] :\ 0 \\ \mathrm{I}_{\mathrm{Par},2} \equiv [\ 0.75\ \mathrm{Par},\ \ 0.85\ \mathrm{Par}\ ] :\ 0 \\ \mathrm{I}_{\mathrm{Par},6} \equiv [\ 1.15\ \mathrm{Par},\ \ 1.25\ \mathrm{Par}\ ] :\ 0 \\ \mathrm{I}_{\mathrm{Par},7} \equiv [\ 1.25\ \mathrm{Par},\ \ 1.35\ \mathrm{Par}\ ] :\ 0 \end{gathered} \qquad (25)$$

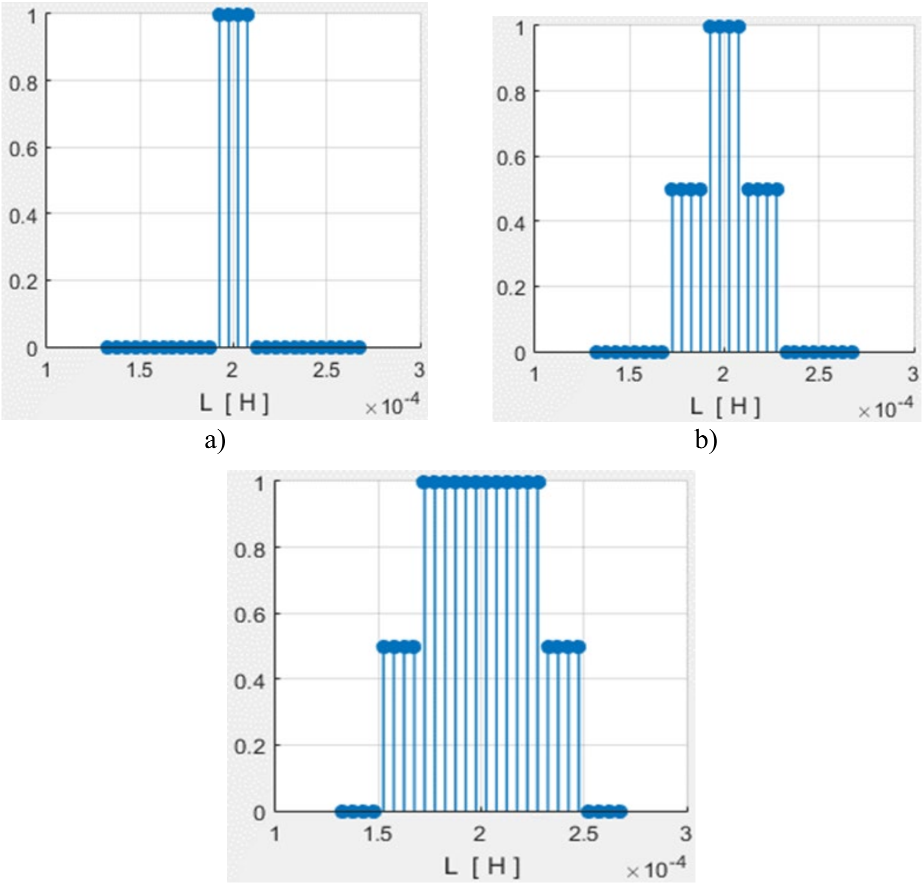
A greater tolerance (35%) and possibility distributions over the upper intervals is used on some parameters in order proper dependences of output characteristics to be explored.

Example 3: Differences from these default degrees are presented in three cases:

Case A1:

$$I_{Par,4} \equiv [\,0.95\ Par,\ 1.05\ Par\,] :\ 1, \qquad Par \in \{E,\ R,\ L\}. \tag{26}$$

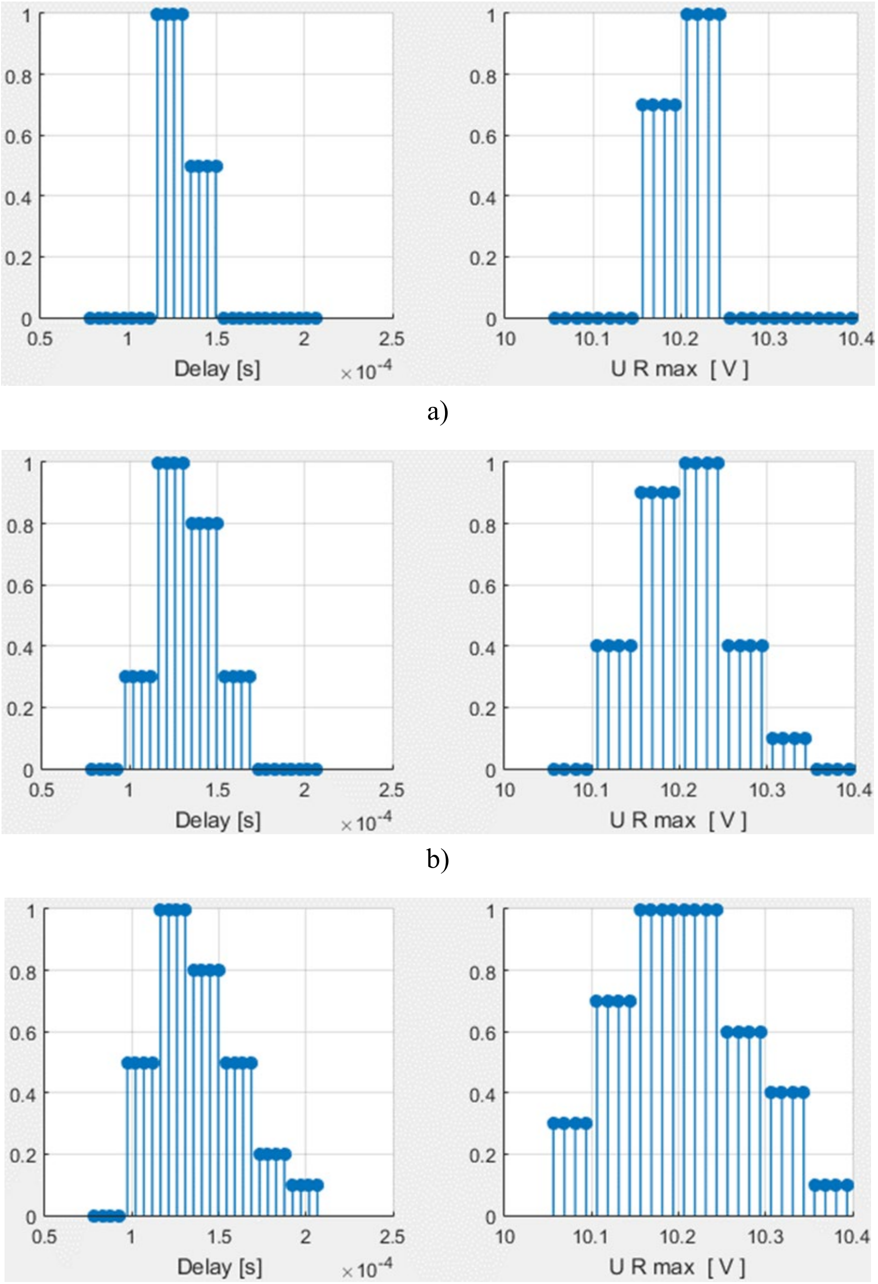
(intervals on *Par* with juxtaposed zero values are not noted). Respective degrees of membership on the inductance are shown on Fig. 1a). Proportional intervals and same degrees on the input voltage and the resistance are used. Single intervals are applied (see (26)).



a) b) c)

Fig. 1. Representations in an authors' software based on three kinds of modeling on the inductance: a) with a single interval; b) with a triangular fuzzy number; c) with a trapezoidal fuzzy number

Case B1: There is no differences (see Fig. 1b). Triangular fuzzy numbers are applied according to (24) on all parameters.



a)

b)

c)

Fig. 2. Results of simulations with authors' software based on three kinds of modeling on the inductance, the input voltage and the resistance: a) with single intervals; b) with triangular fuzzy numbers; c) with trapezoidal fuzzy numbers

__Case C1:__

$$\begin{array}{l}
I_{Par,1} \equiv [\,0.65\,Par,\ \ 0.75\,Par\,] :\ 0.0 \\
I_{Par,2} \equiv [\,0.75\,Par,\ \ 0.85\,Par\,] :\ 0.5 \\
I_{Par,3} \equiv [\,0.85\,Par,\ \ 0.95\,Par\,] :\ 1.0 \\
I_{Par,4} \equiv [\,0.95\,Par,\ \ 1.05\,Par\,] :\ 1.0 \\
I_{Par,5} \equiv [\,1.05\,Par,\ \ 1.15\,Par\,] :\ 1.0 \\
I_{Par,6} \equiv [\,1.15\,Par,\ \ 1.25\,Par\,] :\ 0.5 \\
I_{Par,7} \equiv [\,1.25\,Par,\ \ 1.15\,Par\,] :\ 0.0 \\
\qquad Par \in \{E,\ \ R,\ \ L\}.
\end{array} \tag{27}$$

Respective degrees of membership on the inductance are shown on Fig. 1 c). Trapezoidal fuzzy numbers are applied according to (27) on the inductance, the input voltage and the resistance.

These three cases determine the output voltage parameters, which depend on increasing range on *E*, *R* and *L* (Fig. 2).

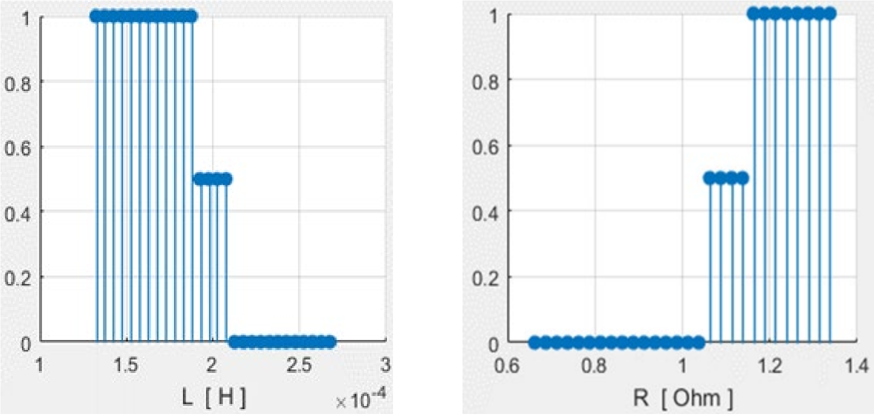
Example 4: Differences from the default degrees are presented in four cases.

__Case A2:__

$$\begin{array}{l}
I_{L,1} \equiv [\,0.65\,L,\ \ 0.75\,L\,] :\ 1.0 \\
I_{L,2} \equiv [\,0.75\,L,\ \ 0.85\,L\,] :\ 1.0 \\
I_{L,3} \equiv [\,0.85\,L,\ \ 0.95\,L\,] :\ 1.0 \\
I_{L,4} \equiv [\,0.95\,L,\ \ 1.05\,L\,] :\ 0.5 \\
I_{R,5} \equiv [\,1.05\,R,\ \ 1.15\,R\,] :\ 0.5 \\
I_{R,6} \equiv [\,1.15\,R,\ \ 1.25\,R\,] :\ 1.0 \\
I_{R,7} \equiv [\,1.25\,R,\ \ 1.15\,R\,] :\ 1.0
\end{array} \tag{28}$$

(here and below intervals on L and R with juxtaposed zero values are not noted). Respective degrees of membership on the resistance and the inductance are shown on Fig. 3. They determine the following degrees of membership on the maximal output voltage intervals via authors' software [4] (Fig, 4):

$$\begin{array}{l}
I_{URmax,1} \equiv [\,10.18,\ \ 10.24\,]\ [V] :\ 0.4 \\
I_{URmax,2} \equiv [\,10.24,\ \ 10.30\,]\ [V] :\ 0.9 \\
I_{URmax,3} \equiv [\,10.30,\ \ 10.36\,]\ [V] :\ 1.0 \\
I_{URmax,4} \equiv [\,10.36,\ \ 10.42\,]\ [V] :\ 0.7 \\
I_{URmax,5} \equiv [\,10.42,\ \ 10.48\,]\ [V] :\ 0.4 \\
I_{URmax,6} \equiv [\,10.48,\ \ 10.54\,]\ [V] :\ 0.2 \\
I_{URmax,7} \equiv [\,10.54,\ \ 10.6\,]\ [V] :\ 0.1
\end{array} \tag{29}$$



a) b)

Fig. 3. Representations in the authors' software based on modeling on: a) the inductance; b) the resistance

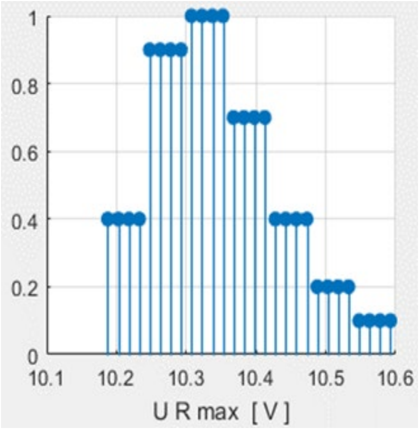


Fig. 4. Results of simulations with authors' software based on membership degrees on the inductance and the resistance

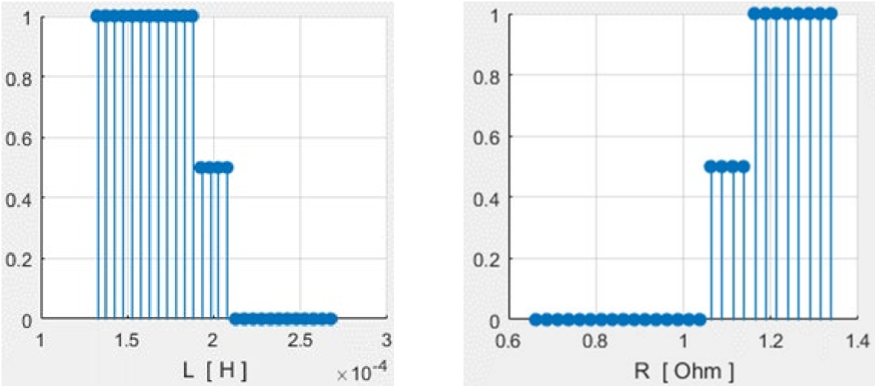
These degrees of membership form value

$$V_{\mathrm{UR}}^{1} = \langle 0.4, \quad 0.9, \quad 1, \quad 0.7, \quad 0.4, \quad 0.2, \quad 0.1 \rangle \tag{30}$$

and fuzzy production rule

$$\text{IF } L \text{ is } \textit{more or less low} \text{ AND } R \text{ is } \textit{high} \text{ THEN } URmax \text{ is } V_{\mathrm{UR}}^{1} \tag{31}$$

(the values on resistance and inductance based on (28) and shown on Fig. 5 are interpreted as “more or less low” and “high” respectively).



a) b)

Fig. 5. Representations in the authors' software based on modeling on: a) the inductance; b) the resistance

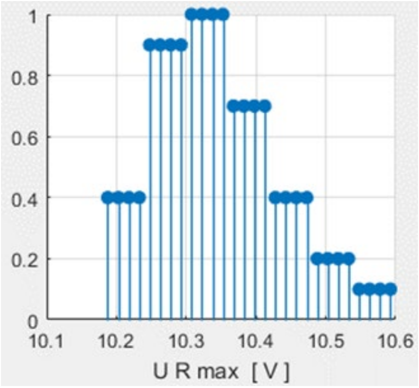


Fig. 6. Results of simulations with authors' software based on membership degrees on the inductance and the resistance

Let the following three degrees on the inductance be presented in the next three cases:

$$\begin{aligned} I_{L,1} &\equiv [\,0.65\,L,\ 0.75\,L\,]: \quad 1\,; \\ I_{L,2} &\equiv [\,0.75\,L,\ 0.85\,L\,]: \quad 1\,; \\ I_{L,3} &\equiv [\,0.85\,L,\ 0.95\,L\,]: \quad 1\,. \end{aligned} \tag{32}$$

Case B2:

$$\begin{aligned} I_{R,6} &\equiv [\,1.\,15\,R,\ 1.25\,R\,]: \quad 1\,; \\ I_{R,7} &\equiv [\,1.25\,R,\ 1.35\,R\,]: \quad 1\,. \end{aligned} \tag{33}$$

The following degrees of membership on the maximal output voltage intervals from (29) are determined by the authors' software according to (32) and (33) in

$$V_{\mathrm{UR}}^{2,1} = \langle 0.3, \quad 0.9, \quad 1, \quad 0.6, \quad 0.2, \quad 0.1, \quad 0 \rangle . \tag{34}$$

They defer from the respective ones in

$$V_{\mathrm{UR}}^{2,2} = \langle 0.4, \quad 0.9, \quad 1, \quad 0.7, \quad 0.4, \quad 0.2, \quad 0.1 \rangle , \tag{35}$$

which is calculated in inference on (31) according to possibility distributions (32) and (33). The resultant mean square error on membership degrees is 11%.

__Case C2:__

$$\begin{aligned} I_{R,5} &\equiv [\ 1.05\ R,\ \ 1.15\ R\ ]:\ \ 0.2 \\ I_{R,6} &\equiv [\ 1.\ 15\ R,\ \ 1.25\ R\ ]:\ \ 1.0 \\ I_{R,7} &\equiv [\ 1.25\ R,\ \ 1.35\ R\ ]:\ \ 1.0 \end{aligned} \tag{36}$$

The respective values on the maximal output voltage intervals determined by the authors' software and an inference on (31), (32) and (36) are

$$V_{\mathrm{UR}}^{3,1} = \langle 0.4,\ \ 1,\ \ 1,\ \ 0.6,\ \ 0.3,\ \ 0.1,\ \ 0 \rangle \tag{37}$$

$$V_{\mathrm{UR}}^{3,2} = \langle 0.4,\ \ 0.9,\ \ 1,\ \ 0.7,\ \ 0.4,\ \ 0.2,\ \ 0.2 \rangle \tag{38}$$

with mean square error 11% too.

__Case D2:__

$$\begin{aligned} I_{R,5} &\equiv [\ 1.05\ R,\ \ 1.15\ R\ ]:\ \ 0.5 \\ I_{R,6} &\equiv [\ 1.\ 15\ R,\ \ 1.25\ R\ ]:\ \ 1.0 \\ I_{R,7} &\equiv [\ 1.25\ R,\ \ 1.35\ R\ ]:\ \ 1.0 \end{aligned} \tag{39}$$

The respective values on the maximal output voltage intervals determined by the authors' software and an inference on (31), (32) and (39) are

$$V_{\mathrm{UR}}^{4,1} = \langle 0.5,\ \ 1,\ \ 0.9,\ \ 0.5,\ \ 0.2,\ \ 0.1,\ \ 0 \rangle \tag{40}$$

$$V_{\mathrm{UR}}^{4,2} = \langle 0.5,\ \ 0.9,\ \ 1,\ \ 0.7,\ \ 0.5,\ \ 0.5,\ \ 0.5 \rangle \tag{41}$$

with mean square error 28%.

4. CONCLUSION

The fuzzy production rules, which are applied on power system parameters gives satisfactory results, mostly in cases in which facts are modeled as fuzzy numbers with supports, which are subsets of cores of fuzzy numbers in these fuzzy production rules (particularly, in the presented Case B2 membership degrees on the voltage match the respective ones from the fuzzy value in the consequent of the rule). More generally, in cases in which facts are modeled as fuzzy numbers, which are subsets of fuzzy numbers in these fuzzy production rules (particularly, in the presented Case C2), the results can be satisfactory too. However, in case in which facts are modeled by a fuzzy number, which is equal to a fuzzy number in the rule, the lowest membership degree matches the lowest membership degree in the support of this fuzzy number (particularly, in the presented Case D2).

The crisp sets are a special case of the fuzzy sets. Therefore, the last ones give more detailed view on possibilities (a given parameter can have various crisp values). Cores and supports of fuzzy sets (as interval estimations) provide less information; such intervals are not considered in the present paper, but they are popular. Indeed, in this case all membership values are equal to one or zero (in a context of the fuzzy sets theory). Particularly, in case A1 supports and cores match with length 0.1 Par, according to (26).

Similarly, in cases B2, C2 and D2, all inductances satisfy (32) with intervals length 0.3 L (in case B2 the resistance satisfy (33) with intervals length 0.2 R).

Generally, the results, which are obtained with the authors' software, are based on many simulations [7-9]. Oppositely, the results, which are obtained with the fuzzy production rules, use simple formulae in order membership degrees to be rapidly estimated. The given mean square errors show the difference between these two approaches.

The concept of the linguistic variables as a tool in approximate reasoning is widely implemented. There are such variables in the present paper too; there are fuzzy values on *Delay* and *URmax* (see Fig. 2), which can be interpreted more or less as "medium", but they are specific, and they do not cover the respective linguistic variable from the table. The used roundings in all membership values are same (as in this table).

The presented approach gives good results in the training of power electronics, as it implements in itself the application of artificial intelligence techniques and modern information and communication technologies. [10-12] On the other hand, with a view to conducting remote studies, issues related to guaranteeing the security and reliability of the data are also important. [13].

ACKNOWLEDGMENT

This work was supported by the European Regional Development Fund within the Operational Programme "Science and Education for Smart Growth 2014 - 2020" under the Project CoE "National center of mechatronics and clean technologies" BG05M2OP001-1.001-0008.

REFERENCES

[1] Y. Peng, H. Wang, Parameters Identification of Buck Converter Based on Dynamic Characteristics. *10th International Conference on Power Electronics and ECCE Asia (ICPE 2019 - ECCE Asia),* 2019, pp. 3071-3076, doi: 10.23919/ICPE2019-ECCEAsia42246.2019.8797155.

[2] V.-D. Andries, L. Goras, A. Buzo, G. Pelz, Automatic tuning for a DC-DC Buck Converter with adaptive controller. *2017 International Symposium on Signals, Circuits and Systems (ISSCS)*, 2017, pp. 1-5, doi: 10.1109/ISSCS.2017.8034938.

[3] B. Babes, A. Boutaghane, N. Hamouda, M. Mezaache and S. Kahla, "A Robust Adaptive Fuzzy Fast Terminal Synergetic Voltage Control Scheme for DC/DC Buck Converter," *2019 International Conference on Advanced Electrical Engineering (ICAEE)*, 2019, pp. 1-5, doi: 10.1109/ICAEE47123.2019.9014717.

[4] N. Nitesh Kumar, Shankaragouda R. Patil, Prabhudeva, Srikanth S., Shama Ravichandran, Feedback Controller Design For A DC-DC Buck Converter. *2021 Fourth International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, 2021, pp. 1-5, doi: 10.1109/ICECCT52121.2021.9616954.

[5] Scarpelli H., F. Gomide, W. Pedrycz, Modeling fuzzy reasoning using high level Petri nets. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, Vol.4, No.1, World Scientific Publishing Company, 1996, pp.61-85, doi: 10.1142/S0218488596000056.

[6] D. Dubois, H. Prade, Possibility theory and its applications: A retrospective and prospective view. *The 12th IEEE International Conference FUZZ '03*, vol. 11, 2003. doi: 10.1109/FUZZ.2003.1209314.

[7] Gochev V.; Gocheva P.; Hinov N., NET implementation of electronic circuit design. *AIP Conference Proceedings*. 2333, 070016, 2021, doi: 10.1063/5.0041606.

[8] Hinov, N., Gocheva, P., Gochev, V., Index Matrices-Based Software Implementation of Power Electronic Circuit Design. *Electronics* (Switzerland), vol.11, no.5, art. 675, 2022, doi: 10.3390/electronics11050675

[9] Gocheva, P., Gochev, V., Hinov, N., Fuzzy Production Rules on Estimations of Buck DC-DC Power Converter Parameters, *2022 International Conference on Information Technologies (InfoTech)*, *Publisher: IEEE,* 15-16 September 2022, Varna, Bulgaria, doi: 10.1109/InfoTech55606.2022.9897073

[10] Kasabov, N. From Multilayer Perceptrons and neuro-fuzzy systems to deep learning machines: Which method to use? – A survey. *International Journal on Information Technologies and Security*, vol. 9, no. 2, 2017, pp. 3-24.

[11] M. Q. Duong, H. Tran, C. A. Hossain, Influence of elemental parameter in the boost and the buck converter. *2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)*, 2017, pp. 528-531, doi: 10.1109/R10-HTC.2017.8289015

[12] M. N. Makar, S. O. Abdellatif, Assessing the Trade-off in the Evaluating Parameters of Various Buck DC-DC Converter Topologies. *2022 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, 2022, pp. 440-443, doi: 10.1109/ISITIA56226.2022.9855210.

[13] Aaron Zimba, Mwenge Mulenga. A dive into the deep: Demystifying WannaCry crypto ransomware network attacks via digital forensics. *International Journal on Information Technologies and Security*, vol. 10, no. 2, 2018, pp. 57-68.

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Manuscript received on 12 October 2022