Proposed Fuzzy Logic Controller for Buck DC-DC Converter

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Abstract – This paper provides the design for buck DC-DC converter system using fuzzy logic as well as sliding mode method. Design of fuzzy logic controller will be based on improvement of imperfection of the sliding mode controller, in particular the robustness and response time of the system. The simulation results of both systems using fuzzy logic and sliding mode are shown as well as compared to signify better of the two.

Keywords- buck; DC/DC converters; Fuzzy logic control

I. Introduction

The dc/dc converters controller techniques have been widely investigated and analyzed in many papers. Among them, linear and nonlinear methods, the most popular are voltage control and current injected control [1]. Controllers based on these techniques are recognized by their simplicity to design and to implement, but their parameters generally depend on the equilibrium point. However, a reduction of the useful bandwidth is observed when large-signal stability is achieved, affecting converter performances. Moreover, application of these techniques to high-order dc/dc converters (e.g. Buck topologies), may result in complexity design of control parameters and difficult stabilization.

In the case of linearity and time invariance of the controlled process cannot be assumed, fuzzy logic control appears very useful, especially when no mathematical model of the process is well-posed, or when human understanding of the process is different from its model [2]. Based on knowledge about how to control a system, fuzzy logic control provides a methodology for manipulating, representing and implementing a humans experience [3]. Human knowledge and expertise are used by fuzzy logic to deal with uncertainties in the process of control [4].

Sliding mode control is a robust control method for the systems, where modeling inaccuracies, disturbances and parameter variations are present [5,6]. This strategy introduced in [7] has the advantages to assure finite time and convergence of the output voltage error to the equilibrium point.

II. System Modeling

To illustrate the controller principal, the state space description of the buck converter under fuzzy logic control [7], where the control parameters are the output voltage error dynamic, output voltage, and capacitor current. Figure (1) shows the schematic diagram of a fuzzy logic controller.

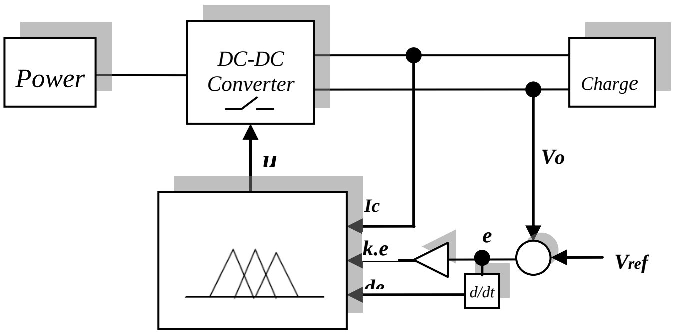

Figure 1. Proposed sl Structure of fuzzy logic regulator.

The output voltage $V_o(t)$ error and the capacitor current $I_C(t)$ are used as state variables, the state space equation involving the simple model is given by:

$$\begin{cases} e = V_o - V_{ref} \\ de = e_k - e_{k-1} \end{cases} \quad (1)$$

Where V_O is the output voltage, V_{ref} is the reference output voltage. Capacitor current I_C is used to delimit the overshoot inductor current at startup. The gain k ensures stability and establishes the desired dynamic and static performance [8].

III. FUZZY LOGIC CONTROLLER

The possibility to design a control system based on a very general kind of inexact information is due to the development of the theory of fuzzy sets and algorithms [9]. This linguistic information may be obtained from a human expert experience. This is obtained from the expert by describing the control strategy used and the way he reacts in a particular situation [10]. Thus, the expert may be able to express this control strategy as a set of linguistic decision rules.

A. Fuzzy Logic Model

The structure of the fuzzy logic model adopted here has three inputs and one output as illustrated in figure (2). The first input is the capacitor current, the second input is the output voltage error and the third input is the derivative of the output voltage error. The outputs illustrate the fuzzy logic control (*u*) of the DC-DC converter switch. These inputs are represented by two fuzzy membership functions for the first input and three membership functions for each second and third input , resulting in a total of 35 fuzzy rules. The system has a single output representing the stabilizing signal.

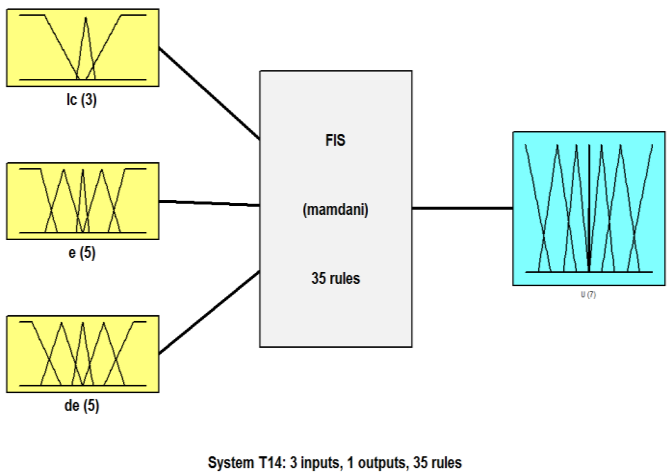

Figure 2. Proposed fazzy logic control circuit for buck DC-DC converter.

The input variables in a fuzzy control system are mapped by sets of membership functions, known as “fuzzy sets”. The fuzzification is a process of connecting an input value to a fuzzy value. A fuzzy control system can also incorporate the analog inputs of 0, 1 into its fuzzy functions that are either one value or another [5]. The input membership functions for each of the three inputs are depicted in figure (3).

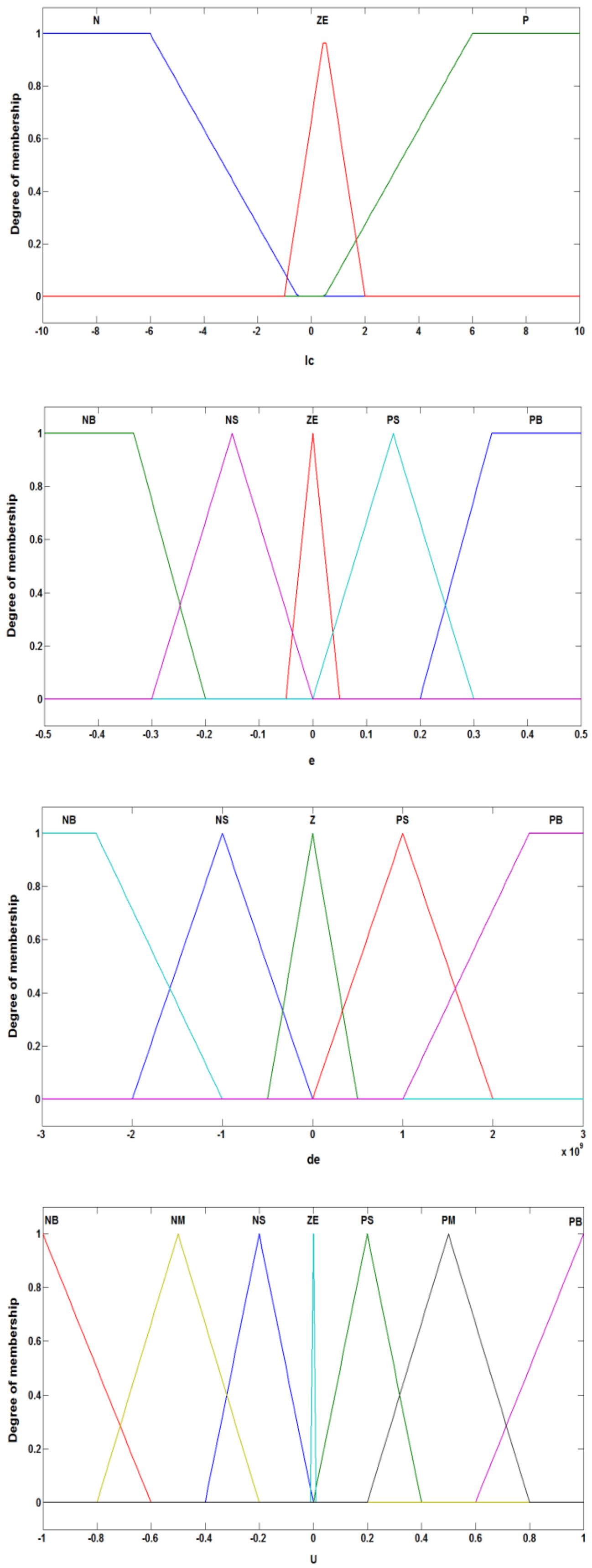

Figure 3. Membership functions for *Ic*, *e*, *de* and *u*.

Rule table of fuzzy controller: (a) if I_C is ZE (Zero) and (b) combination of *e* and I_C. Fuzzy Control applies fuzzy logic to the control of processes by utilizing different parameters, usually 'error' and 'change in error', for the process state and applying rules to decide which level for the output. The linguistic variables used for the input and output are often of the form 'negative large', 'positive small', 'zero' etc. A typical rule base for a two-input and single output with three membership functions per variable are shown in Table (I) and table (II).

TABLE I. RULE TABLE IF I_C IS ZE (ZERO)

e \ *de*	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NM	ZE
NS	NB	NM	NS	ZE	PM
ZE	NB	NS	ZE	PS	PB
PS	NM	ZE	PS	PM	PB
PB	ZE	PM	PB	PB	PB

TABLE II. SPECIFICATIO COMBINATION OF *E* AND I_C

I_C \ *e*	NB	NS	ZE	PS	PB
N	ZE	PS	PB	PB	PB
P	NB	NB	NB	NS	NB

The fuzzy decision surface is in a three-dimensional space to examine the degree of nonlinearity that this fuzzy stabilizer is capable to produce. This fuzzy decision surface, shown in figure (4), plots the fuzzy output versus the two inputs.

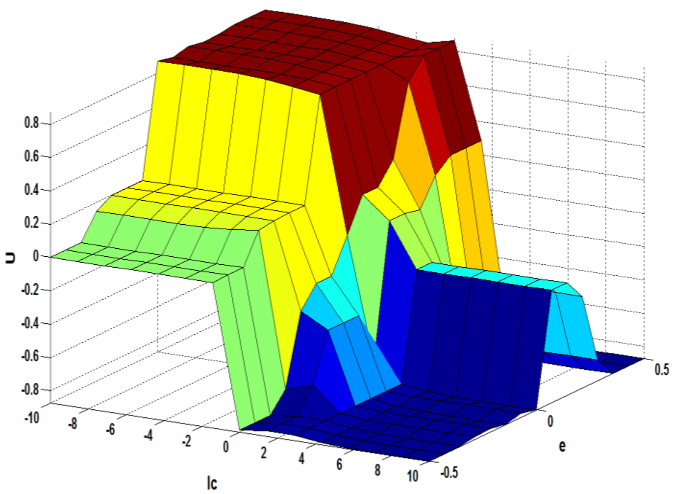

Figure 4. Surface plot of *u* as a function of *e* and *de.*

IV. SIMULATION RESULTS

Simulink of Matlab is used to carry out simulations. The theoretical design conducted on the buck converter described below is validate by the simulation results of the proposed fuzzy logic controller. The results are compared to sliding mode controller proposed in [7]. The parameters of the system used are V_i = 10V, V_o = 28V, V_{ref} = 5V, L = 125mH, C = 250µF, R_L = 15Ω, and f_S = 100kHz.

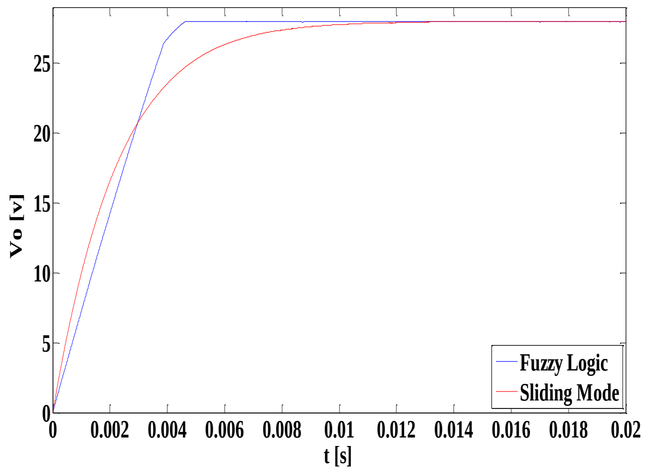

Figure 5. Time responses of output voltage V_o.

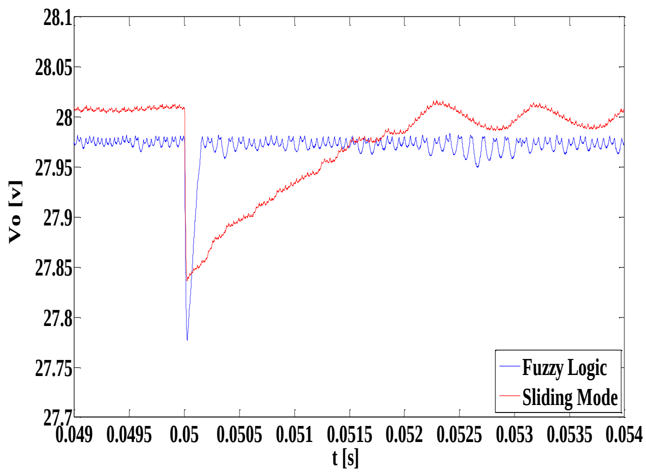

Figure 6. Transient responses of *Vo* due to R_L a step change from 15 Ω to 5 Ω at t = 0.05 s.

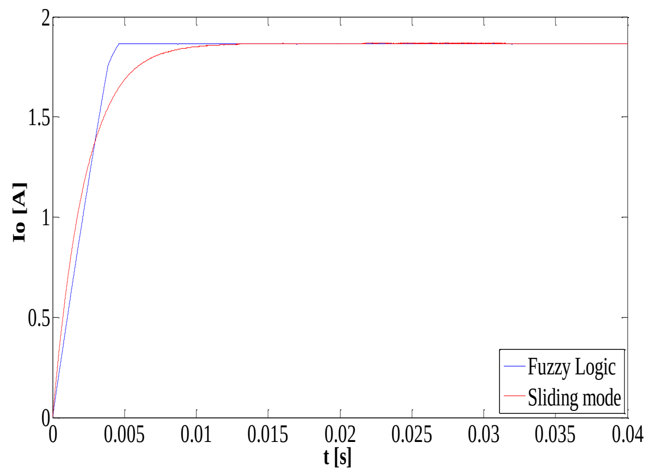

Figure 7. Time responses of output current *Io*.

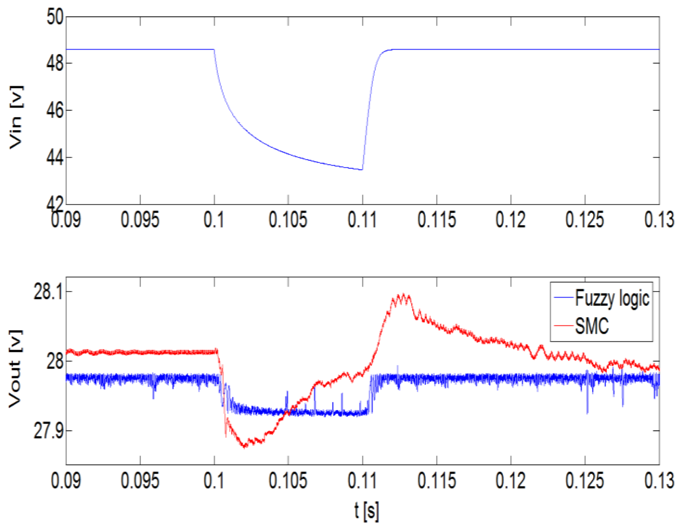

Figure 8. Transient response of *Vo*, due to perturbation in the input voltage V_{in} at t=0.1s.

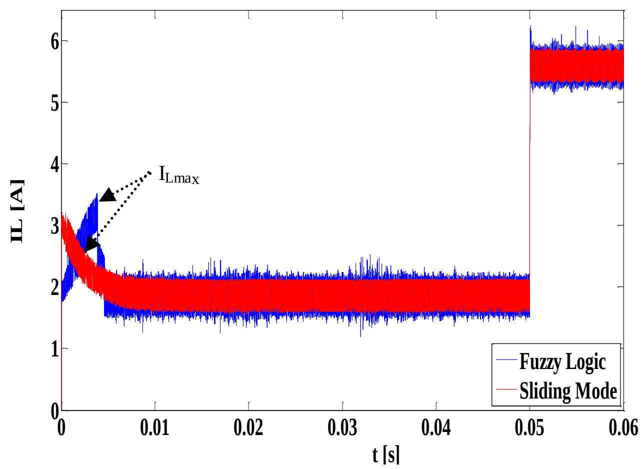

Figure 9. Time response and Transient response of inductor current I_L due to a step change in R_L from 15 Ω to 5Ω at t = 0.05 s.

The controller performances are studied using a load resistance step change from 5Ω to 15Ω for constant switching frequency of 100kHz. The figures below show respectively the simulated output voltage, output current and inductor current waveform. The startup load resistor was set to R_L=15Ω. The transient responses are due to a step change in R_L from 15Ω to 5Ω at t=0.05s. It is appear from figure (5-6) that the output voltage tracks successfully its reference in all cases, the time response and the transient response of the fuzzy logic is faster and stable than the SMC strategy. The output current I_o transient response, obtained by the fuzzy logic in figure (7) is more stable than that obtained by the SMC. The transient responses of the output voltage are due to a step change in V_i, it is clear from figure (8) that the output voltage obtained by fuzzy logic strategy is faster and stable than that obtained by the SMC. Figure (9) shows the transient responses due to drop voltage in V_i, the fuzzy logic strategy offer very stable response compared to the SMC strategy where we can see oscillation due to this drop voltage, however, the I_L overshoot current is more higher for the ANFIS strategy than the SMC in figure (9).

V. Conclusion

In order to improve the performance of sliding mode controller, design and simulation of a fuzzy logic controller was proposed. Compared to the sliding mode controller, the study of the proposed fuzzy control show an improvement in the transitional state, and reduction of the fluctuations in steady state. The introduction of intelligent controllers in DC-DC converter is very promising. They achieved very good performances, fast responses with no overshoot, robustness to charge and input voltage variation and less fluctuation in the steady state.

Acknowledgements

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References

[1]. R.Redl, N.Sokal, "Current-Mode control, five different types, used with the three basic classes of power converters: small-signal AC and large-signal DC characterization, stability requirements, and implementation of practical circuits", IEEE-PESC, 1985, pp. 771-785.

[2]. P. Isomursu, T. Rauma, "A self-tuning fuzzy logic controller for temperature control of superheated steam", Fuzzy Systems, IEEE World Congress on Computational Intelligence., Proceedings of the Third IEEE Conference, Vol.3,1994.

[3]. K. M. Passino, S. Yurkovich, Fuzzy control , Addison Wesley,1998.

[4]. M. S. I. Md., S. Z. Sarker, K. A. A. Rafi, M. Othman, "Development of a fuzzy logic controller algorithm for air conditioning system", ICSE Proceedings,2006.

[5]. S. C. Tan, Y. M. Lai, M. K. H. Cheung, and C. K. Tse, On the practical design of a sliding mode voltage controlled buck converter, IEEE Trans. Power Electron., vol. 20, no. 2, pp. 425–437, Mar. 2005.

[6]. G. Spiazzi, P. Mattavelli, L. Rossetto, L. Malesani, Application of Sliding Mode Control to Switch-Mode Power Supplies, Journal of Circuits, Systems and Computers (JCSC), Vol. 5, No. 3, September 1995, pp.337-354.

[7]. M.Bensaada, A.Boudghene Stambouli, “A practical Design Sliding Mode Controller for DC-DC Converter Based on Control Parameters Optimization Using Assigned Poles Associate to Genetic Algorithm“, Elsevier International Journal of Electrical Power & Energy Systems (JEPES), Volume 53, December 2013, Pages 761-773.

[8]. Nakoula, Y. "Apprentissage des Modèles linguistiques flous, par Jeu de Règles Pondérées", Thèse de Doctorat, Université de Savoie, France, Juillet 1997.

[9]. Zadeh,L.A., “Fuzzy Sets”, Information and Control, 8.pp.338-3 53, 1965.

[10]. Earl Cox, “Fuzzy Fundamentals”, IEEE Spectrum, pp. 58-61. October 1992.