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AN ADAPTIVE CURRENT MODE FUZZY LOGIC CONTROLLER FOR DC-TO-DC CONVERTERS

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***Abstract* – In this paper is presented a new fuzzy logic controller (FLC) using inductor current feedback for significantly improving the dynamic performance of dc-to-dc converters. Inductor current plays an important role in high performance dc-to-dc converter control and FLC is suitable to deal with time-varying nonlinear nature of power converters.**

The presented approach is general and can be applied to any dc-to-dc converter topologies. Controller implementation is relatively simple and can guarantee a small-signal response as fast and stable as for other standard regulators and an improved large-signal response. Simulation results of Boost converter show control potentialities.

Keywords*: current mode, fuzzy logic controller, digital control, adaptive.*

1. INTRODUCTION

In this paper is presented a new current mode fuzzy logic control method. This new control law is based on the introduction of inductor current feedback into the inner control loop of converter system, where FLC serves as the outer control loop. The proposed topology combines the merits of both the conventional FLC and current mode control in digital implementation. This methodology can be easily applied to many converter topologies such as Buck, Boost, Buck-Boost and Sepic.

DC-to-DC converters have been predominately controlled by analog integrated circuit technology and linear system design techniques. In recent years, with the rapid development of advanced high-speed digital circuits, digital control will gradually replace the currently used analog controller in high frequency switching converters. The intelligent power supplies are expected to play an important roll in aerospace, communication, and automobile industries in the near future [1].

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are difficult and sometime even impossible to be described using traditional methods.

One example in dc-to-dc converter is to describe then severances of converters system disturbances accurately. Fuzzy set the any has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy control is built up by a group of rules based on the human knowledge of system behavior. Simulink simulation model is built to study the dynamic behavior of dc-to-dc converter and performance of proposed controllers.

In addition, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Therefore, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters.

The basic scheme of a fuzzy logic controller is shown in figure 1 and comprises four principal components: a **fuzzyfication interface**, which converts input data into suitable linguistic values; **a knowledge base**, which consists of a data base with the necessary linguistic definitions and the control rule set; **a decision-making logic** which, simulating a human decision process, infers the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; **a defuzzification interface** which yields non-fuzzy control action from an inferred fuzzy control action [2].

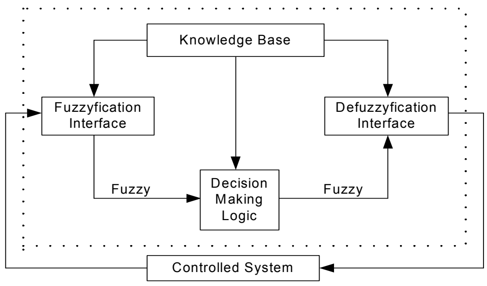

Figure 1. Basic configuration of FLC

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model. Fuzzy logic

controller has been proven to be superior to the conventional PID controller in that it naturally provides the ability to deal with highly nonlinear, time-variant and ill defined systems where the mathematical models are difficult to be obtained or the control variable are too hard measure.
Simulation is performed in Boost converter to verify the proposed fuzzy logic controllers. The results confirm that the proposed method achieve much better robustness and adaptability in terms of load change, in input voltage and output voltage variation. Its present better dynamic performance, such as small overshoot, more damping and fast transient time for Boost converter.

2. BASICS OF FUZZY LOGIC CONTROLLERS USING INDUCTOR CURRENT FEEDBACK

It is well know that the inductor current plays a very important role in dynamic response of dc-to-dc converter. It can provide additional information on the energy stored in the converter. In this paper, the proposed fuzzy logic control using inductor current feedback is implemented with two control loops, it sees in figure 2 [3].

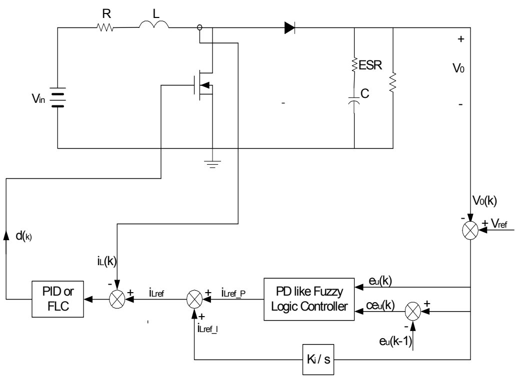

Figure 2. Block diagram of current mode fuzzy logic controller using i_L in the inner control loop

The converter is represented by a "black box", from which we only extract the terminals corresponding to input voltage v_{in}, output voltage v_0 one inductor current i_L.
In figure 3 is presented the equivalent circuit model. The Simulink model for the Boost converter is developed based on the circuit equations [4]:

$$L\frac{\mathrm{d}i_L}{\mathrm{d}t} = v_{in} - v_0(1-d) - i_L R_L, \tag{1}$$

$$C\frac{\mathrm{d}v_0}{\mathrm{d}t} = i_L(1-d) - \frac{v_0}{R_0}, \tag{2}$$

$$v_0 = v_c + R_C(i_L(1-d) - i_0), \tag{3}$$

where i_L, v_0, v_{in} is inductor current, output voltage and supply voltage. d is the duty cycle, R_0 is the load resistor and R_L is the winding resistor of the inductor.
Equation (2) can be rewritten as

$$i_L = \frac{C}{1-d}\frac{dv_0}{dt} + \frac{1}{1-d}\frac{v_0}{R_0}. \tag{4}$$

Of equation (4) it observes that the inductor current contains the information about the derivates of the output voltage. By using the inductor current into FLC, the dynamic response of whole system could be significantly improved.

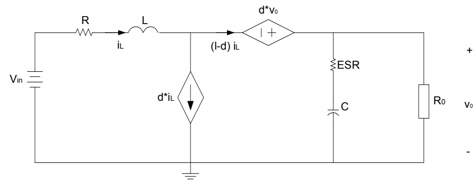

Figure 3. Average circuit model of Boost converter

The outer voltage loop is implemented by a PD like fuzzy logic controller with digital integrator it serves as the reference of the inductor current, and a PID or FLC controller controls the inner current loop.
The inputs of PD like FLC are defined as the error of voltage $e_u(k)$ and change of error $ce_u(k)$.
Fuzzy sets is defined for each input and output variable. Seven fuzzy level (NB, NM, NS, Ze, PS, PM, PB) are defined for $e_u(k)$ and $ce_u(k)$ the membership functions triangular ones with 50% overlap. The membership functions of output variable i_{Lref_P} are seven triangular fuzzy set values. The min-max method of inference engine is used. The defuzzify method used in this FLC is center of area. The fuzzy control rules for the voltage loop are shown in table1.

Table I.The rule base of FLC

ce/e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The output of fuzzy logic controller i_{Lref-P} is proportional part of reference current. Combined with

the output of integrator i_{Lref-I}, it constitutes the reference current signal, $i_{Lref} = i_{Lref-P} + i_{Lref-I}$.
The fuzzy logic controller will play the role of a PD, which ensures very fast dynamic response. Digital integrator is added to cancel the steady state error and will act only around the reference value [1].
In the inner control loop, the difference between inductor current and the reference current signal i_{Lref} is processed by a fuzzy logic controller, which will generate the duty cycle *d*.
In figure 4 are presented the control surface for the two controllers.
The new FLC propose using inductor current feedback has significant advantages; first, using the inductor current feedback improves load transient response, second because the change in the inductor current is sensed earlier than the change in the output voltage, the proposed control algorithm achieves instantaneous correction action against line voltage changes without having to wait for the sensed output voltages change to pass through the relatively long delay in a conventional FLC, without current feedback.

3. RESULTS

To verify the proposed fuzzy logic controllers, simulation by using Matlab/Simulink is performed using dc-to-dc Boost converter. The parameters of Boost converters are:
$V_{in} = 24\text{V}, V_0 = 48\text{V}, \quad \text{R}_\text{L} = 0{,}04\Omega.\ L = 24\mu\text{H},$
$C = 220\mu F, \text{R}_\text{C} = 0{,}03\Omega, \quad R_0 = 19{,}2\Omega.$
In figure 5 is shown the diagram realized in Simulink for simulation model, it is built to study the dynamic behavior of dc-to-dc converter and performance of proposed controllers.
In figure 6 is presented the variation of output voltage in time when all of the controller parameters regulated at rated operating condition and then kept unchanged; considering the dynamic performance, the proposed algorithm is verified under large variation load current from 1,25 to 2,5A in Boost converter, as shown in figure 7, and figure 8 is presented simulation on output reference voltage changes from 48V to 54V at rated input voltage and current load are performed.

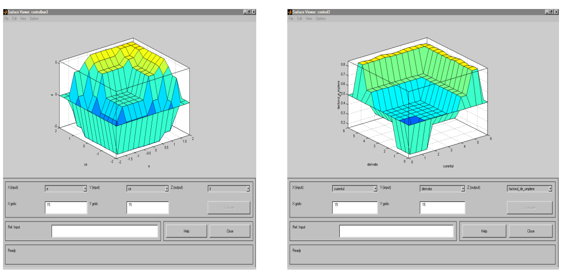

Figure 4. The surfaces control of FLC

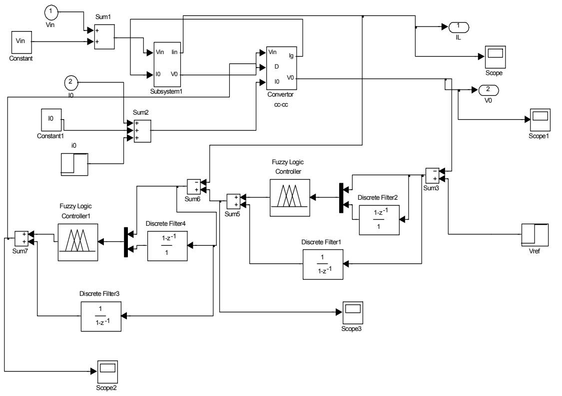

Figure 5. Diagram block realized in Simulink for simulation model

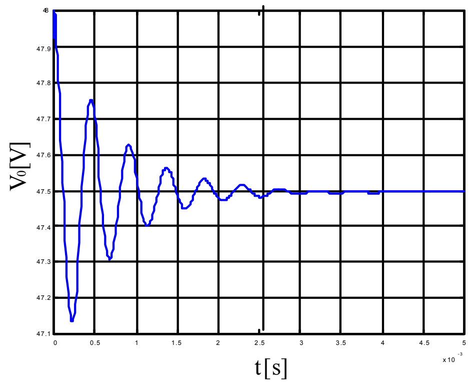

Figure 6. The output voltage response at rated operating condition

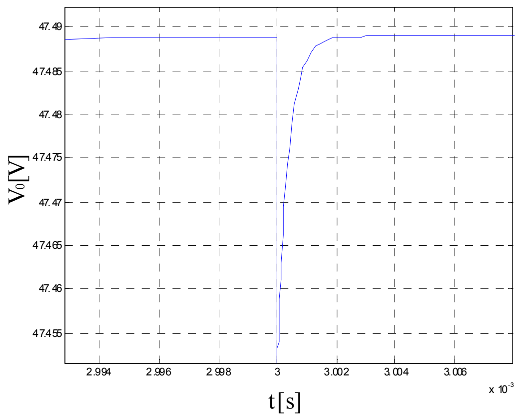

Figure 7. The output voltage response to load current change of 1,25 to 2,5A

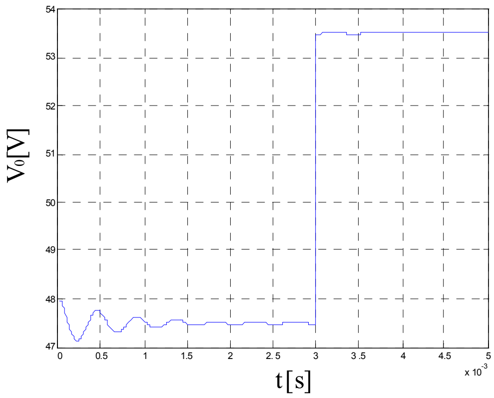

Figure 8. The output reference voltage changes from 48V to 54V

4. CONCLUSIONS

A new controller for dc-to-dc converters based on the fuzzy logic control is presented; it contains inductor current feedback into the inner control loop of converter system. With the feedback of inductor current, the proposed scheme combines the advantages of both the conventional FLC and current mode control.

As compared to standard controllers, it provides improved performances in terms of overshoot limitation and sensitivity to parameters variations.

This new methodology can be easily applied to many converter topologies such as Buck, Boost, Buck-Boost and Sepic.

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