On the Design of Fuzzy-Controlled KY Converter

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***Abstract*—In this paper a fuzzy controller is designed for a recently developed voltage-boosting converter, named KY converter. The fuzzy controller neatly controls the switches of a 2nd-order KY converter via pulse-width-modulation (PWM) technology, which yields the voltage conversion ratio 2-plus-D where D represents the duty cycle. Experimental results show that the design simultaneously achieves faster transient load responses and lower output voltage ripples as compared with the conventional boost converters.**

Keywords-fuzzy controller; KY converter; pulse-width-modulation

I. INTRODUCTION

DC/DC converters have been used in a wide variety of engineering applications. Buck and boost converters are the two basics, and several variations have been addressed. In view of the conventional non-isolated voltage-boosting converters, such as the boost converters and the buck-boost converters, their output currents are pulsating, thereby causing the corresponding output voltage ripples to tend to be large. Recently, new circuit topologies aiming at reducing output voltage ripples have been presented, e.g., [1-2]. In [1], coupling inductors have been used in the boost/buck-boost converters. In [2], an interleaved control scheme has been utilized. Both designs yield low output voltage ripples, but the presence of one right-half plane zero under the continuous current mode (CCM) makes it difficult to concurrently achieve fast transient load responses. To overcome this problem, a new voltage-boosting converter, named KY converter has recently been developed [3-4]. In this paper, a fuzzy controller design is introduced to the 2-plus-D KY converter of [4].

II. ANALYSIS OF 2-ORDER KY CONVERTER

Fig. 1 shows the scheme of a 2nd-order KY converter, which consists of four MOSFET switches S_{11}, S_{12}, S_{21} and S_{22} along with four body diodes D_{11}, D_{12}, D_{21} and D_{22} respectively, two diodes D_1 and D_2, two energy-transferring capacitor C_{b1} and C_{b2} which are large enough to keep the voltages across themselves approximately constant at some values, one output inductor L, and one output capacitor C. This scheme is scheduled to be operated in the following two modes: Mode 1: S_{12} and S_{21} are turned on and S_{11} and S_{22} are turned off, and Mode 2: S_{11} and S_{22} are turned on and S_{12} and S_{21} are turned off. The detailed analysis is as follows.

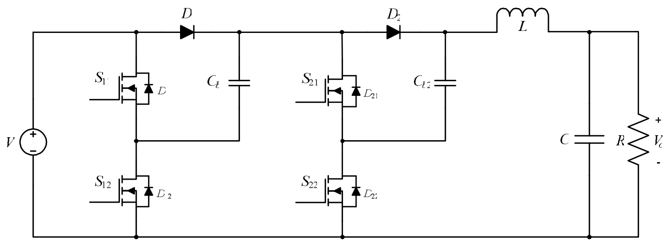


Figure 1. Second-order-derived KY converters.

Mode 1: The corresponding power flow is shown in Fig. 2. As soon as S_{12} and S_{21} are turned on and S_{11} and S_{22} are turned off, the voltage across L is equal to the voltage v_i across C_{b1} plus the voltage $2v_i$ across C_{b2}, and then minus the output voltage v_o, thereby causing L to be magnetized. On the other hand, the current flowing through C is equal to the current i flowing through L minus the current flowing through R. Hence, the dynamical equations read

$$L\frac{di}{dt} = 3v_i - v_o \text{ and } C\frac{dv_o}{dt} = i - \frac{v_o}{R} \tag{1}$$

Mode 2: The corresponding power flow is shown in Fig. 3. As soon as S_{11} and S_{22} are turned on and S_{12} and S_{21} are turned off, in the same way, we can get

$$L\frac{di}{dt} = 2v_i - v_o \text{ and } C\frac{dv_o}{dt} = i - \frac{v_o}{R} \tag{2}$$

By applying voltage-second balance to (1) and (2), the relationship between DC input voltage Vi and DC output voltage Vo can be represented as

$$\frac{V_o}{V_i} = 2 + D \tag{3}$$

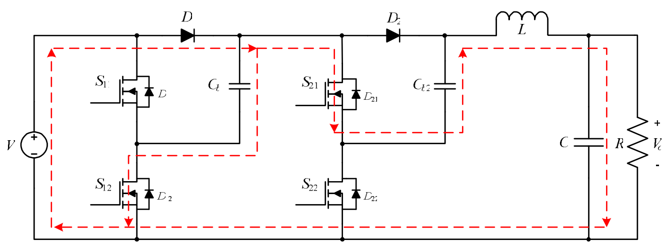


Figure 2. Power flow of the 2-plus-D converter in mode 1.

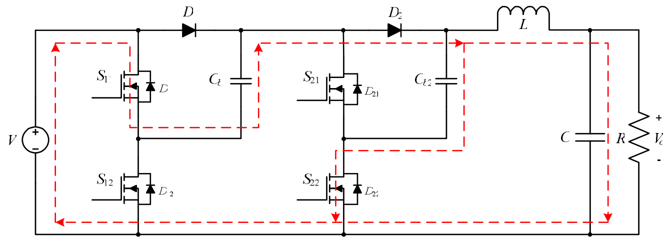


Figure 3. Power flow of the 2-plus-D converter in mode 2.

III. FUZZY CONTROLLER DESIGN

Fuzzy logical control is introduced to control the operation of the switches of the 2nd-order KY converter. As shown in Fig. 4, the inputs of the designed fuzzy logical controller are output voltage error *e* and its error rate *de*. The output is *F*. For convenience, the numerical domains of the three can be normalized and defined in a unified manner as follows: *e*, *de*, *F* = {0, 15, 27, 35, 43, 55, 70}. The corresponding collections of fuzzy sets are {NB, NM, NS, ZE, PS, PM, PB}, which represent negative-big, negative-middle, negative-small, zero, positive-small, positive-middle, positive-big, respectively. Their membership functions are shown in Fig. 5, 6, and 7.

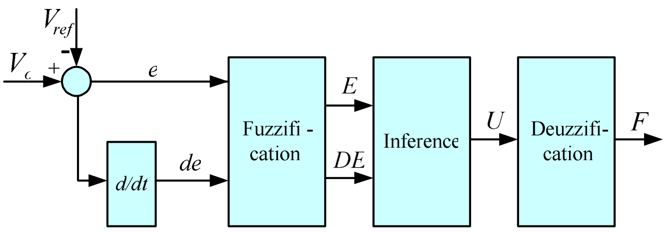


Figure 4. Structure of fuzzy controller.

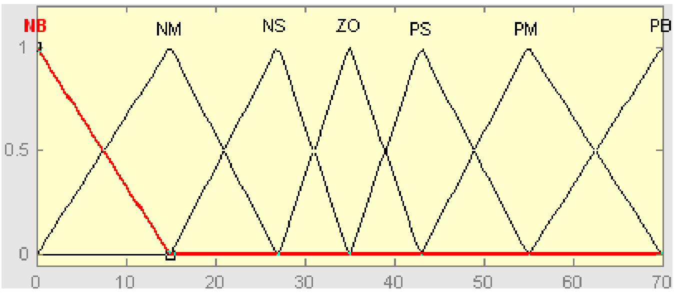


Figure 5. Membership function of E.

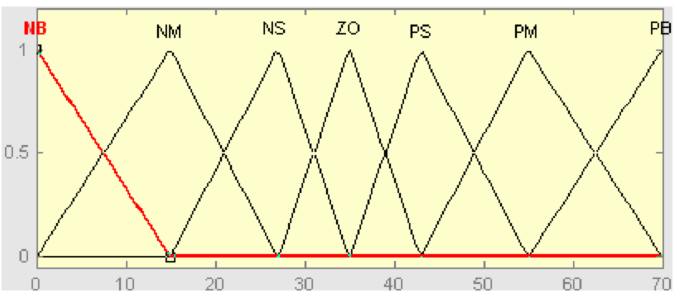


Figure 6. Membership function of DE.

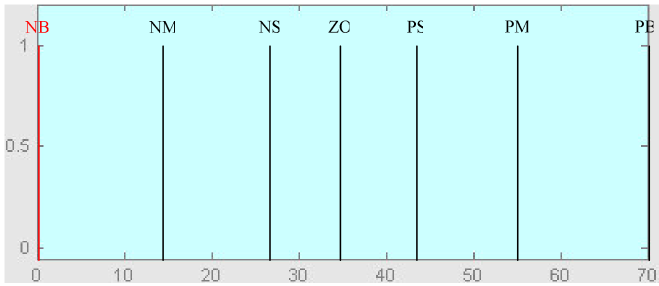


Figure 7. Membership function of U.

The establishment of the fuzzy logical control rules is based on the characteristics of the 2nd-order KY converter and the errors previously defined. For example, when the error is negative-big and the error rate is negative, this implies this output voltage tends to decrease further. In order to correct this phenomenon, we may send a positive-big output F to reduce the duty cycle. Based on the output voltage error and its error rate, 49 fuzzy control rules can be designed, as shown in Table 1. Finally, the weighted average method is used to carry out the fuzzy operation.

TABLE I. 49 FUZZY CONTROL RULES.

F		*E*						
		NB	NM	NS	ZO	PS	PM	PB
DE	NB	PB	PB	PB	PM	PS	ZO	NS
	NM	PB	PB	PM	PS	ZO	NS	NM
	NS	PB	PM	PS	ZO	NS	NM	NB
	ZO	PB	PM	PS	ZO	NS	NM	NB
	PS	PB	PM	PS	ZO	NS	NM	NB
	PM	PM	PS	ZO	NS	NM	NB	NB
	PB	PS	ZO	NS	NM	NB	NB	NB

IV. SIMULATION

The experimental setting is specified as follows: (i) rated input voltage is set to 12V; (ii) rated output voltage is set to 28V; (iii) rated output power is 50W; (iv) switching frequency is set to 200kHz; (v) output inductance *L* is chosen to be 5μH; (vi) one 680μF OSCON connected in parallel with one 100μF MLCC is selected for C_{b1}, and the other one is for C_{b2}; and (vii) one 1000μF RUBYCON connected in parallel with one 100μF MLCC is chosen for *C*.

In the following Figs. 8 and 9 show the simulation results due to various transient load responses. Specifically, Figs 8 and 9 present the measured transient load responses due to load change from 100% to 0% at 0.002s and 0% to 100% at 0.003s of the rated load, respectively. In view of these results, it is obvious that the undershoots/overshoots of the transient load responses are within 50mV, and the corresponding recovery times are within 50µs.

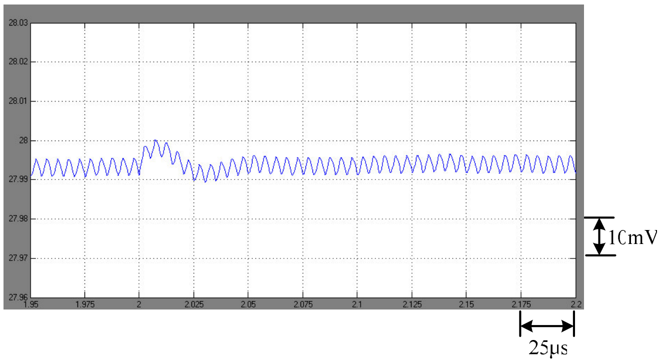


Figure 8. Simulated transient load response due to load change from 100% to 0%.

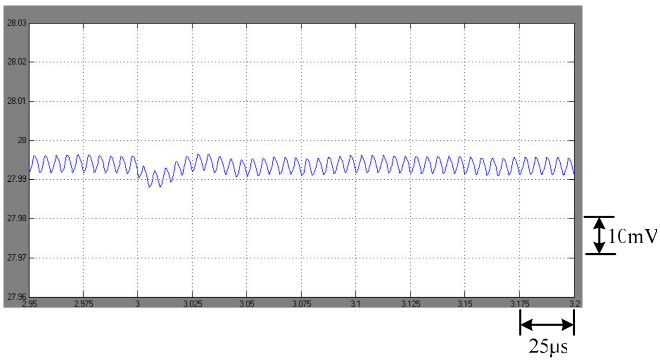


Figure 9. Simulated transient load response due to load change from 0% to 100%.

V. EXPERIMENTAL RESULTS

Fig. 10 shows the block diagram of the implemented fuzzy-controlled KY converter with the same design parameters specified in Section IV. The field programmable gate arrays (FPGA) experimental board is used to implement the proposed fuzzy controller whose parameters are tuned according to the transient load responses of the KY converter from no load to rated load. The feedback error signal plugged to the fuzzy controller is obtained via subtracting the reference voltage from the digitalized output voltage, and then sent to FPGA with a system clock of 20MHz to create the corresponding PWM control signals M11, M12, M21, and M22 for driving the MOSFET switches. According to the proposed operation rules, if M11 and M12 are always in the low level, then this converter operates in the KY converter; otherwise, this converter operates in the 2-plus-D converter.

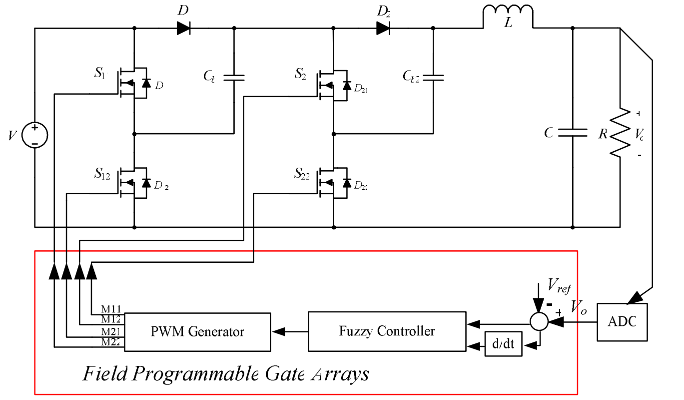
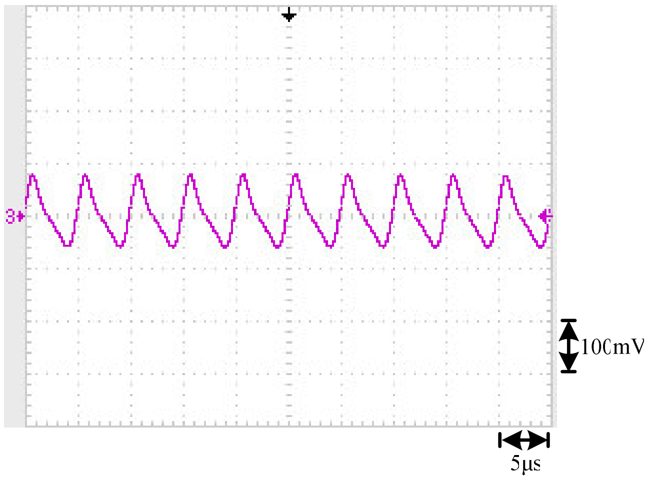
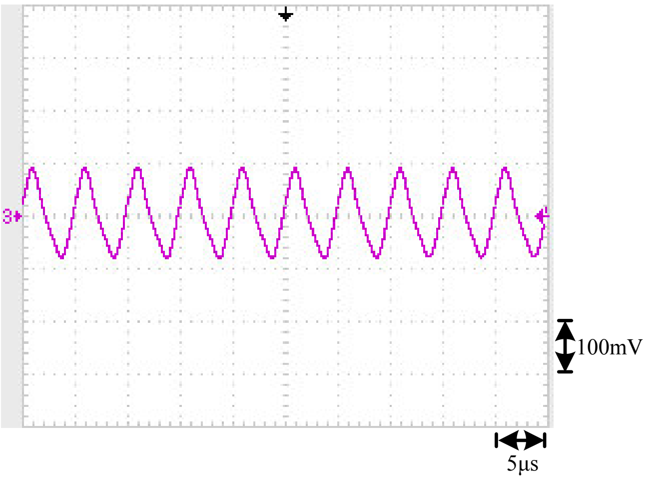


Figure 10. Block diagram of the overall system.

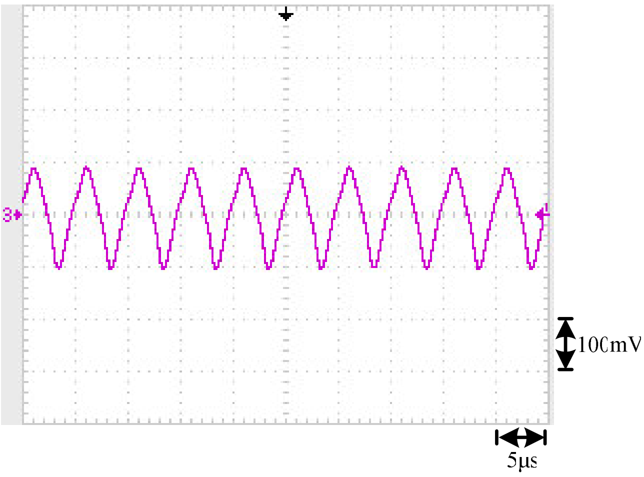
Figs. 11 to 13 depict the experimental results of the steady-state output voltage and the various load transient responses under the proposed fuzzy control. Specifically, Fig. 11 shows the steady-state output voltage ripples at the cases of no load, middle load and rated load, respectively. Fig. 12 shows the steady-state output voltage 28V. Fig. 13 presents the measured load transient responses due to load changes from 100% to 0% and 0% to 100% of rated load, respectively. It is shown that good output regulation has been achieved, undershoots/overshoots of the load transient responses are within 200 mV, and the corresponding recovery times are within 75μs. In addition, all the output voltages ripples are within 200 mV. The results demonstrate that the proposed fuzzy controller renders the 2-plus-D KY converter with good dynamic responses in terms of fast load transient responses and low output voltage ripples.



(a)



(b)



(c)

Figure 11. The steady-state output voltage ripples. (a) At no load (0A). (b) At middle load (1A). (c) At rated load (2A).

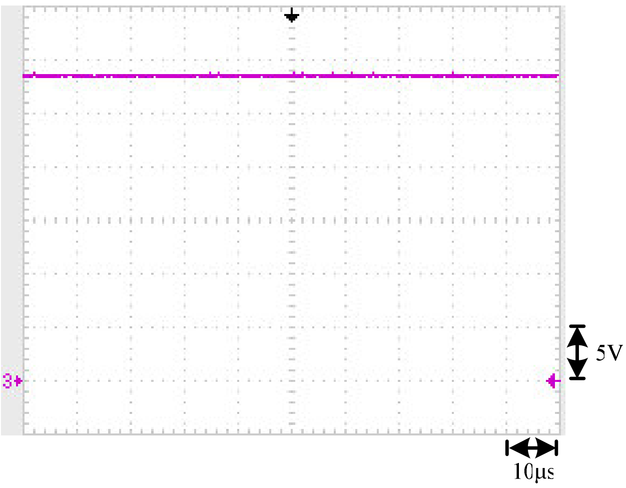
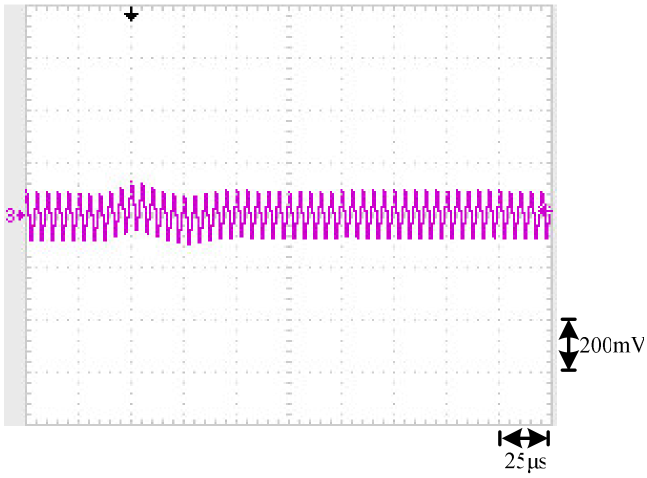
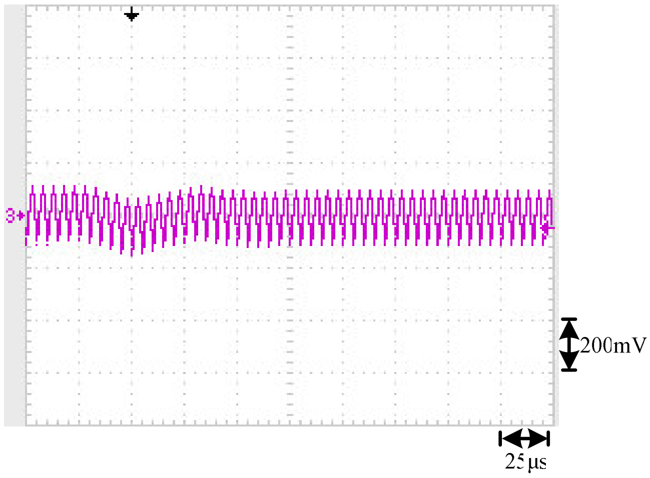


Figure 12. The steady-state output voltage 28V.



(a)



(b)

Figure 13. Measured load transient response due to load change for the 2-plus-D converter. (a) From rated load to no load. (b) From no load to rated load.

VI. CONCLUSION

A fuzzy logic controller design for a 2nd-order KY converter has been presented. Experimental results have shown that good output regulation has been achieved, and better dynamic responses were obtained, compared to conventional boost converters, in terms of fast transient load responses and low output voltage ripples.

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