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FUZZY-BASED STEP-DOWN DC-DC CONVERTER FOR A WIND POWER GENERATION SYSTEM

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ABSTRACT: This approach presents a scheme based on fuzzy logic control for a step-down dc-dc converter, so that the described converter can generate a constant output voltage, which is lower than the input voltage, using closed-loop compensation in a resistance load. The fuzzy controller requires faster and more accurate response compared with that of proportional-integral (PI) control. Finally, to verify the competitive performances and the excellent stability, experiments are performed for a wind power generation system to compare the output performances between the fuzzy controller and the PI controller just by my experiments.

Keywords: step-down dc-dc converter; wind power generation system; fuzzy set theory.

1. INTRODUCTION

For the wind generation system, the input resource power varies considerably, where variable speed generation is more attractive than fixed speed systems [1]. Therefore, in this paper a step-down dc-dc converter for wind power generation system is proposed to obtain competitive control performances in the occasion of varied output loads and to compare with the PI controller.

An increasing demand for dc-dc converters with high efficiency and high accuracy is presented for electric circuits with stable output voltage. Various circuit designs are proposed to meet advantages of wide load current range, high efficiency and low output voltage ripple, such as switching regulator [2], charge-storage-diode snubber circuit [3], RCD snubber [4], fault tolerant H-bridge [5], and so on. As for designing a dc-dc converter, varieties of circuits have been implemented. Zhu and Luo [6] propose a theoretical analysis for the continuous and discontinuous conduction modes using the switched capacitor and self-lift techniques. Lee *et al.* [2] present low-output-ripple step-down dc-dc converter, which cascades a buck converter with a low-dropout regulator. A push-pull circuit with switching bidirectional dc-dc converter is discussed by Hiraki *et al.* [7] to reduce snubber losses of power electronic energy storage systems. And the combination of step up/down dc-dc converter is presented by Seol *et al.* [8] to simultaneously obtain the advantages of step up/down dc-dc converters.

Because of emphasizing the conversion efficiency, control accuracy and low output voltage ripple, in literature, dc-dc converters with various advanced controllers have been proposed. An optimal pulse-width-modulated control of dc-dc power converters is presented by Ho *et al.* [9] to minimize the ripple magnitude, the leakage voltage and the sensitivity of the output load voltage. Zhou and Rincon-Mora [10] present a dc-dc converter for battery-powered applications to adaptively regulate the current ripple and optimize switching losses. Current-mode control based on backstepping control scheme for dc-dc power converter that has been proposed by Alvarez-Ramirez *et al.* [11] is employed to achieve the robust convergence criterion. For stability analysis suffering from the circuit parameter uncertainty, Lam and tan [12] present a fuzzy controller for employed in switching dc-dc converters that operates in large-signal domain to achieve a conservative result. To successfully control power electronic converters and to guarantee the stability of the control system under input-voltage and load-resistance variations, Cheng *et al.* [13] develop a fuzzy-neural sliding-mode control system. Common dc-dc converters, which are used in complex environments, are achieved, in which a robust controller for a buck converter [14] is designed and those good performances and the system stability can be verified by simulations.

The main goal of this paper is to present a scheme for a step-down dc-dc converter to maintain the stability characteristic and to reduce the total computational load. In this paper, we propose a fuzzy logic control for a step-down dc-dc converter to obtain competitive control efforts. In the following the block diagram of the presented step-down dc-dc converter is depicted as in Fig. 1. The wind power source V_{in} is connected with a buck converter, where the constant output voltage V_o can be regulated by the compensator throughout the PWM modulation for varied resistance loads.

2. FUZZY CONTROL ALGORITHM

When establishing the dynamic model, human operators usually encounter complex patterns of quantitative conditions, which are difficult to interpret accurately. The magnitude of the measurements is usually described as very big, big, small, very small, etc. To represent such inexact information, a nonmathematical approach called "fuzzy set theory" was developed by Zadeh [15].

The block diagram of practical fuzzy step-down dc-dc converter is depicted in Fig. 2, where the fuzzy logic controller is employed to compensate the effects of a resistance load and uncertainties, so that the stability of the dc-dc converter can be confirmed.

The control input of the buck power stage $v_c(t)$, referring to Fig. 2, can be computed by The fuzzy inference mechanism, where $e(t)$ is the error signal, which is computed by subtracting the feedback voltage of the dc-dc converter dynamics from the command of the wind transformer generation, and $v_c(t)$ is the actuating control input of the dc-dc converter from the fuzzy controller to stimulate the step-down dc-dc converter.

3. FUZZY CONTROLLER DESIGN FOR A STEP-DOWN DC-DC CONVERTER

Based on fuzzy set theory, the associated fuzzy sets involved in the fuzzy control rules are defined and listed as follows:

SPB: positive very big; PB: positive big; PM: positive medium; PS: positive small; SPS: positive very small; ZE: zero; SNS: negative very small; NS: negative small; NM: negative medium; NB: negative big; SNB: negative very big.

Here, universes of discourse of the error signal $e(t)$, its derivative $\dot{e}(t)$, and the control input $v_c(t)$ of buck power stage are all assigned and shown in Fig. 3. The membership functions for the fuzzy sets corresponding to $e(t)$, $\dot{e}(t)$, and $v_c(t)$ are defined in Fig. 3.

Because those 11 fuzzy subsets are respectively defined in terms of $e(t)$ and $\dot{e}(t)$ to compute the control input of the buck power stage, the fuzzy inference mechanism contains 121 rules. The two-dimensional symmetrical rule table with 121 rules is shown in Table 1.

The control input of buck power stage $v_c(t)$, can be calculated by the center-of-gravity defuzzification as

$$v_c(t) = \sum_1^{11} u_n \times U_n / \sum_1^{11} u_n \qquad (1)$$

where U_n is the membership function, U_n is the universe of discourse, and U_n is the number of contributions of rules.

To avoid the heavy computational problem for implementing fuzzy control, the method of lookup table is proposed. The aforementioned rules in Table 1 are then combined to form a decision table for the fuzzy controller. The table consists of values showing the different situations experienced by the dc-dc converter and the corresponding control input functions. The lookup table for output voltage regulation of dc-dc converter is given as in Table 2.

4. EXPERIMENTAL VALIDATIONS

In this section, Evaluation of the proposed fuzzy controller design scheme of dc-dc converter for a wind power generation system consisting of switching frequency 10kHz of PWM circuit and the power rating 60W of the Buck converter with type WSP-5C are conducted, so that the fuzzy-based controller is employed for that purpose and the configuration is shown in Fig. 4. Its rated power is 60W with driven motor 1HP, and the motor speed is in the range of 0~60Hz.

The experiments of fuzzy-based dc-dc converter are proposed to apply to a voltage regulation system of a wind power generation. In fact, the control system is, in general, composed of generating a control law as equation (1) to converge the system origin error to zero as time approaches to infinity.

The appealing effect of the fuzzy logic control is given in Fig. 5, which shows the present output voltage of the dc-dc converter, the wind speed of the wind power generation, and the motor speed of the wind generation machine simultaneously. From the upper figure in Fig. 5, the solid line denotes the current output voltage of dc-dc converter, where the dashed line denotes the desired voltage. We can see that the current and desired voltage are coincident with each other, that is, the voltage regulation effect is almost totally fulfilled after 14 seconds, for that output voltage error is less than 3%. This is to show

Table 1
Rule Base with 121 Rules

Fuzzy sets	*SNB*	*NB*	*NM*	*NS*	*SNS*	*ZE*	*SPS*	*PS*	*PM*	*PB*	*SPB*
SPB	ZE	SNS	SNS	NS	NS	NM	NM	NB	NB	SNB	SNB
PB	SPS	ZE	SNS	SNS	NS	NS	NM	NM	NB	NB	SNB
PM	SPS	SPS	ZE	SNS	SNS	NS	NS	NM	NM	NB	NB
PS	PS	SPS	SPS	ZE	SNS	SNS	NS	NS	NM	NM	NB
SPS	PS	PS	SPS	SPS	ZE	SNS	SNS	NS	NS	NM	NM
ZE	PM	PS	PS	SPS	SPS	ZE	SNS	SNS	NS	NS	NM
SNS	PM	PM	PS	PS	SPS	SPS	ZE	SNS	SNS	NS	NS
NS	PB	PM	PM	PS	PS	SPS	SPS	ZE	SNS	SNS	NS
NM	PB	PB	PM	PM	PS	PS	SPS	SPS	ZE	SNS	SNS
NB	SPB	PB	PB	PM	PM	PS	PS	SPS	SPS	ZE	SNS
SNB	SPB	SPB	PB	PB	PM	PM	PS	PS	SPS	SPS	ZE

Table 2
Lookup Table

$\dot{e} \backslash e$	*SNB*	*NB*	*NL*	*NM*	*NS*	*ZE*	*PS*	*PM*	*PL*	*PB*	*SPB*
SPB	1.25	1.13	1.05	0.93	0.85	0.53	0.45	-0.17	-0.25	-3.67	-3.75
PB	1.37	1.25	1.13	1.05	0.93	0.85	0.53	0.45	-0.17	-0.25	-3.67
PL	1.45	1.37	1.25	1.13	1.05	0.93	0.85	0.53	0.45	-0.17	-0.25
PM	1.57	1.45	1.37	1.25	1.13	1.05	0.93	0.85	0.53	0.45	-0.17
PS	1.65	1.57	1.45	1.37	1.25	1.13	1.05	0.93	0.85	0.53	0.45
ZE	1.97	1.65	1.57	1.45	1.37	1.25	1.13	1.05	0.93	0.85	0.53
NS	2.05	1.97	1.65	1.57	1.45	1.37	1.25	1.13	1.05	0.93	0.85
NM	2.67	2.05	1.97	1.65	1.57	1.45	1.37	1.25	1.13	1.05	0.93
NL	2.75	2.67	2.05	1.97	1.65	1.57	1.45	1.37	1.25	1.13	1.05
NB	6.17	2.75	2.67	2.05	1.97	1.65	1.57	1.45	1.37	1.25	1.13
SNB	6.25	6.17	2.75	2.67	2.05	1.97	1.65	1.57	1.45	1.37	1.25

feasibility of the experiments and to show well the results of voltage regulation of dc-dc converter with motor speed in the range of 0~60Hz. To verify the competitive robustness and excellent stability, experiments are performed for a wind power generation system to compare the output performances between the fuzzy controller and the PI controller. Control effects of the PI control are given as in the Fig. 6 to compare output voltage performances of the dc-dc converter.

From Fig. 7 of my experiments, we have found that the steady state of the fuzzy controller is smaller than that of PI controller. And other performances, such as rise time, settling time, and overshoot, can be shown as in Table 3. From Table 3, the fuzzy controller has better performances respectively for rise time, settling time, and overshoot. Finally, we can conclude that the proposed controller is more competitive.

Table 3
Comparison performances

Controller type	*Rise time (sec)*	*Settling time (sec)*	*Overshoot (%)*
Fuzzy control	3	13.5	0
PI control	3.3	14	0.2

5. CONCLUSIONS

We have presented a fuzzy controller design scheme of dc-dc converter for a power generation system. Experiments are conducted on fuzzy and PI control for validation. From the experimental validation, the time of states hitting the desired value. So we can conclude that the fuzzy control is more superior compared to the PI controller. In summary, the present work has provided a scheme that can effectively be applied to the control of the step-down dc-dc converter for wind power generation systems.

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Appendix 1
PI Controller Design for a Step-down DC-DC Converter

The block diagram of practical PI step-down dc-dc converter is depicted in Fig. 8, where the PI controller is employed to compensate the effects of a resistance load and uncertainties, so that the stability of the dc-dc converter can be confirmed.

The PI controller consists of proportional and integral control parts, which can be expressed as

$$v_c(t) = K_P e(t) + K_I \int_0^t e(t)dt \,, \qquad (2)$$

where $e(t)$ is the error signal, which is computed by subtracting the feedback voltage of the dc-dc converter dynamics from the command of the wind transformer generation, and $v_c(t)$ is the actuating control input of the dc-dc converter from the PI controller to stimulate the step-down dc-dc converter.

To improve performances of the dc-dc converter, different coefficients K_P and K_I may be chosen to fulfill the better system requirements. In general, the coefficient, proportional gain K_P, reduces rising time, i.e. if the K_P is more big, the system response is more quickly. If the K_P is chosen to be a big value, the system response will have a higher overshoot and even that the dc-dc converter is unstable. Otherwise, it makes response slow and decreases the precision adjustment for the voltage regulation system. To eliminate the steady state error, the proportional control can not be used generally. The coefficient, integral gain K_I, can be varied to effectively remove the steady state error for the dc-dc converter, but that will make the transient response of the voltage regulation system worse. In this experiment, the proportional gain and integral gain are set as $K_P = 2$ and $K_I = 104$, respectively.

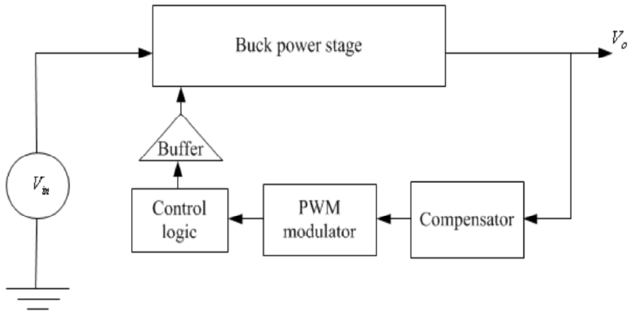


Figure 1: Block Diagram of Step-down DC-DC Converter

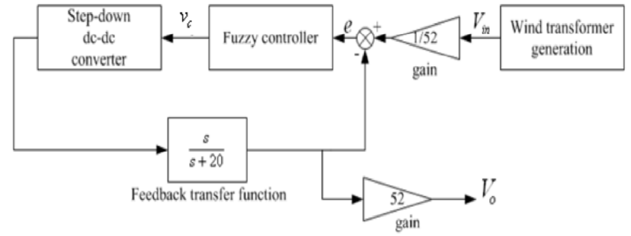
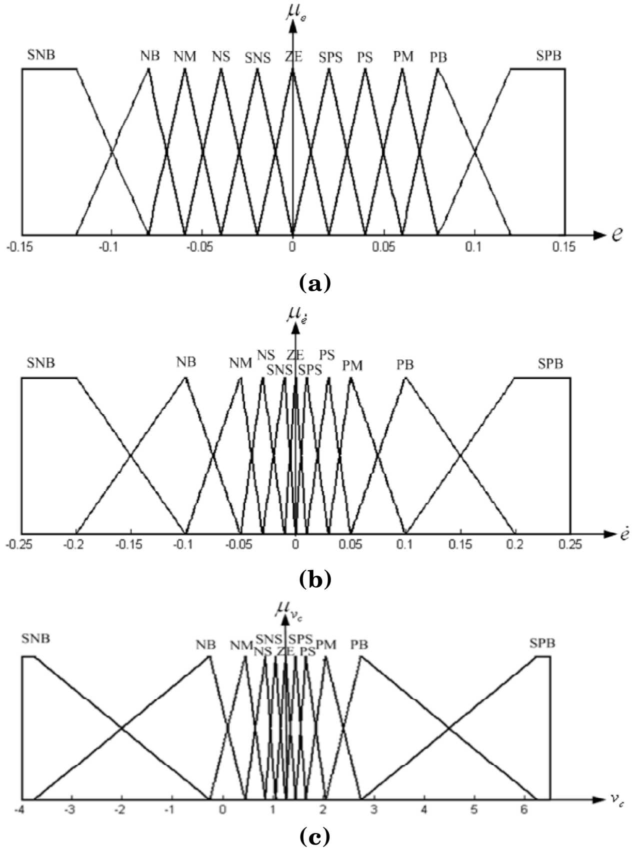


Figure 2: Block Diagram of Practical Fuzzy Step-down DC-DC Converter



(a)

(b)

(c)

Figure 3: Membership Functions of Fuzzy Sets

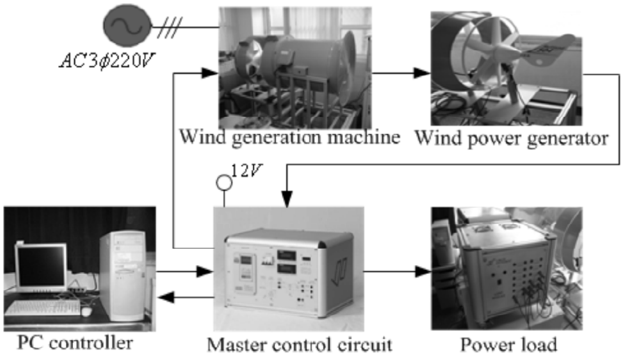


Figure 4: Configuration of Wind Power Generation System

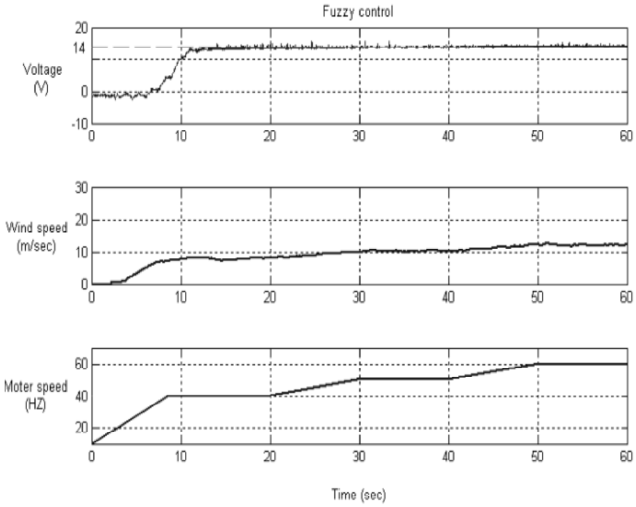


Figure 5: Voltage Response of Fuzzy Controller under Motor Speed in the Range of 0~60Hz

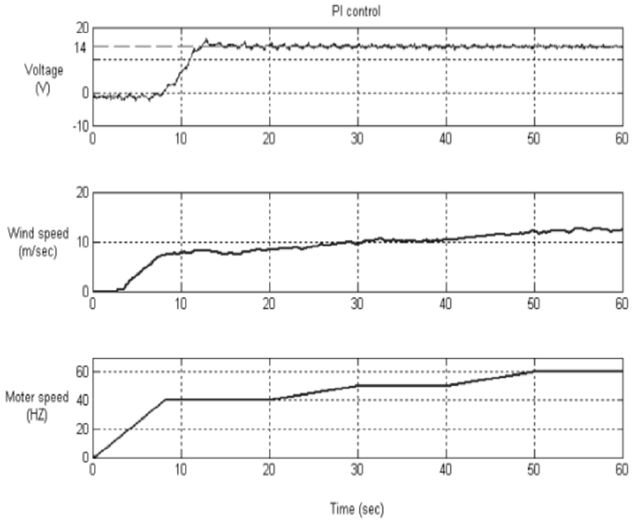


Figure 6: Voltage Response of PI Controller under Motor Speed in the Range of 0~60Hz

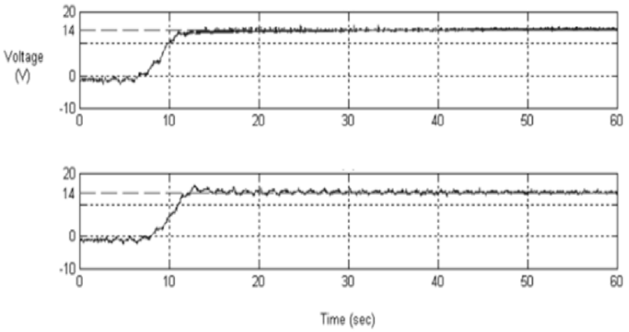


Figure 7: Compared Voltage Responses with Motor Speed in the Range of 0~60Hz (a) Fuzzy Control (b) PI Control

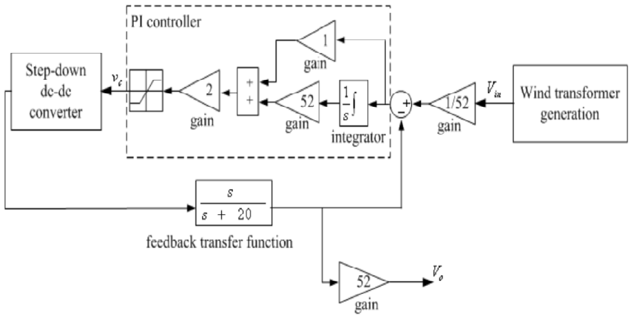


Figure 8: Block Diagram of Practical PI Step-down DC-DC Converter