

A fuzzy control system of diesel generator speed

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Abstract—Diesel generator, in which the generator is driven by the diesel engine to generate alternating current which frequency should keep stable and constant, is broadly used as mobile, urgent or field power source. The alternating current frequency is determined by the diesel speed. So the diesel speed should keep stable and constant too. This paper introduces two analogue control systems: rigid feedback and constant-speed feedback control system, and constructs a fuzzy control system of the diesel speed. Comparison of their control performances and practical applications indicate that the fuzzy control method is feasible and better than the others.

Keywords- control system; fuzzy; diesel generator; speed

I. INTRODUCTION

Diesel generator is broadly used as mobile, urgent or field power source. In diesel generator system the generator is driven by diesel to produce alternating current. So the current frequency produced by diesel generator is determined by the diesel speed. As power source the current frequency should keep stable and constant, such as 50HZ, so the diesel speed should keep stable and constant too. According to the national standard the transient speed regulation ratio of the diesel speed should be smaller than 5%, and the stable speed regulation ratio should not exceed 2%. But because of generator load variation and disturbances the diesel speed fluctuates frequently. So how to keep the diesel speed stable is a very significant problem [1-2].

A lot of work has been done on the control method of diesel generator speed [3-4]. The most popular control methods of diesel generator speed in applications are analogue control methods such as rigid feedback and constant-speed feedback control method [5-6]. There are also some other control methods introduced in the literature [7-8]. Recently an increasing number of work has focused on digital control methods of diesel generator speed such as Neural Networks control method [9] and digital PID control method [10]. Actually diesel generator speed control problem is a nonlinear control problem. According to the results of related research fuzzy control method is an effective method to nonlinear control problem [11-12]. This paper constructs a fuzzy control method for the diesel generator speed. Comparison of the control performances of the analogue control methods and the fuzzy control method and practical applications indicate that the fuzzy control method is feasible and better than the others.

Following the first section, Sect. 2 introduces two analogue control systems of the diesel speed and their control performances. Sect. 3 constructs a fuzzy control system for the diesel speed. Finally comparison of the performances of the control methods presented in this paper and an application of the fuzzy control method are presented in Sect. 4.

II. ANALOGUE CONTROL SYSTEMS OF DIESEL SPEED

A. Diesel Mathematic Models

According to [5-6], the mathematic model of diesel can be written as

$$T_a \frac{d\varphi}{dt} + T_g \varphi = -\xi - \alpha_N \quad (1)$$

Where T_a is diesel acceleration time constant, φ is diesel speed relative variation, T_g is diesel speed recovery constant, ξ is pump plunger angle variation, and α_N is diesel load relative variation.

The mathematic model of diesel speed sensitization element is

$$T_r^2 \frac{d^2\eta}{dt^2} + T_k \frac{d\eta}{dt} + \delta_n \eta = \varphi \quad (2)$$

Where T_r is speed sensitization element time constant, η is slide valve relative displacement, T_k is liquid friction time constant, and δ_n is governor instability.

B. Rigid Feedback Servo Mechanism Mathematic Model

According to [5-6], the mathematic model of rigid feedback servo mechanism is

$$T_s \frac{d\xi}{dt} + B \xi = \eta \quad (3)$$

Where T_s is servo mechanism time constant, and B is rigid feedback coefficient.

C. Constant-speed Feedback Sservo Mechanism Mathematic Model

The mathematic model of constant-speed feedback servo mechanism is

$$T_s \frac{d\xi}{dt} + B\varepsilon = \eta \quad (4)$$

And

$$T_i \frac{d\varepsilon}{dt} + \varepsilon = \beta_0 T_i \frac{d\xi}{dt} \quad (5)$$

Where T_i is constant-speed servo time constant, ε is constant-speed servo compensation piston relative displacement, and β_0 is proportion constant.

D. Diesel Speed Analogue Control Methods

According to the mathematic models presented in Sect. 2.1, 2.2 and 2.3, letting $T_a = 3$, $T_g = 0.9$, $T_r^2 = 1.6 \times 10^{-6}$, $T_k = 7 \times 10^{-4}$, $\delta_n = 0.04$, $T_s = 0.02$, $B = 4$, $T_i = 0.4$, $\beta_0 = 1.1$, and α_N be a step load disturbance which means 100% load change, we can construct the rigid feedback and constant-speed feedback control system of the diesel speed, which are shown in Fig. 1 and Fig. 2 respectively.

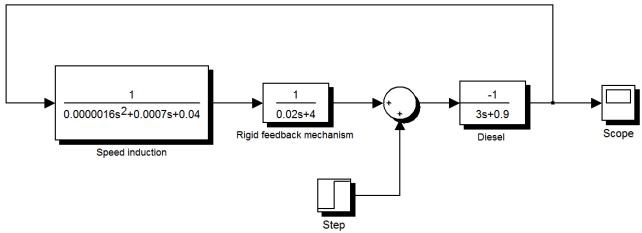


Figure 1. Diesel speed rigid feedback control system.

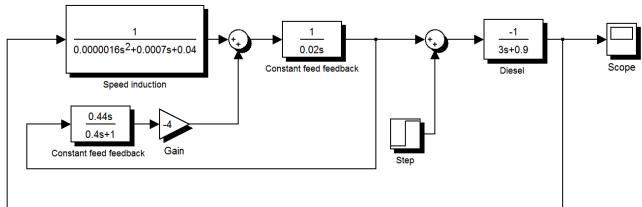


Figure 2. Diesel speed constant-speed feedback control system.

The control performances of rigid feedback and constant-speed control system obtained by the means of simulation are shown in Fig. 3 and Fig. 4 respectively.

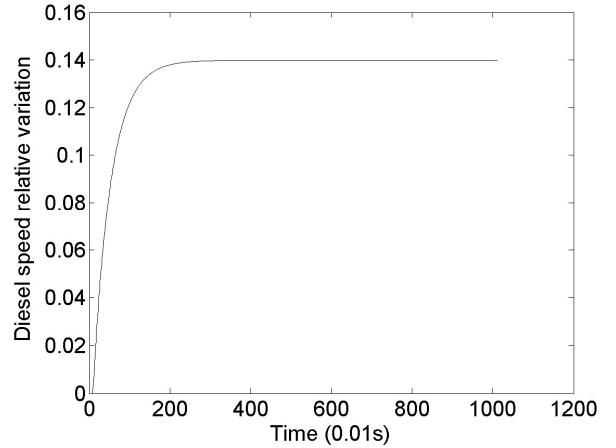


Figure 3. The control performance of rigid feedback control system ($T_a = 3$)

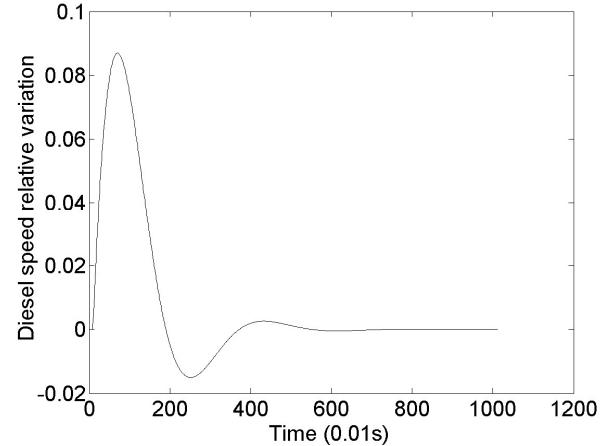


Figure 4. The control performance of constant speed feedback control system ($T_a = 3$)

III. DIESEL SPEED FUZZY CONTROL SYSTEM

In order to construct the fuzzy control system, we use diesel speed relative variation e and its derivative ce as the input variables of the fuzzy controller. The output variable of the fuzzy controller is voltage v that is used to control actuating mechanism, which mathematic model is (3). The linguistic set of e , ce , or v is {NB, NM, NS, ZO, PS, PM, PB}. The universe of discourse of input variable e or ce is $(-6, 6)$ and that of output variable v is $(-3, 3)$. Triangular membership function is adopted here as the membership functions of input and output which are shown in Fig. 5 and Fig. 6 respectively.

Because each of the linguistic sets of the input variable e and ce has 7 members, we can construct 49 control rules for the fuzzy control system, which are shown in Table 1. As the fuzzy controller has two input variables, the antecedent of each control rule has two parts. So fuzzy operator “AND”, which

means minimum, is used to combine the two parts of the antecedent to obtain a single number that represents the result of the antecedent for that rule. Then the result is applied in the implication process to obtain the fuzzy set of the output. The implication method used here is “AND” that means minimum. The implication process should be implemented for each rule.

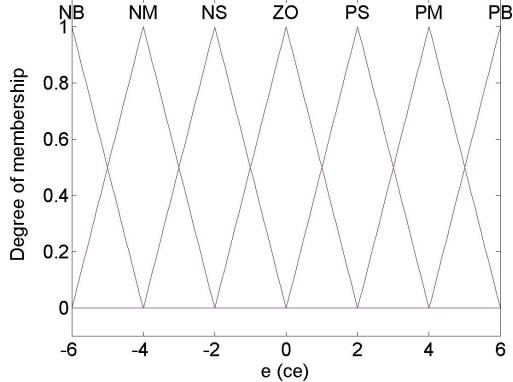


Figure 5. The membership fuction of input variable e or ce

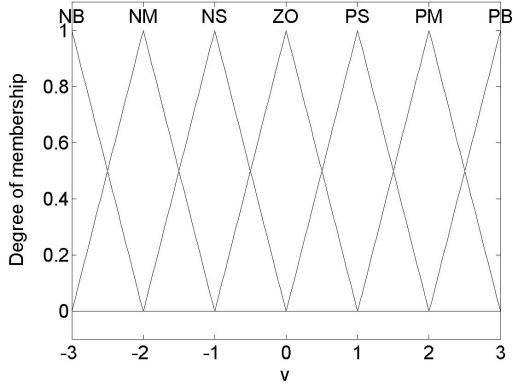


Figure 6. The membership fuction of output variable v

TABLE I. CONTROL RULES OF THE FUZZY CONTROL SYSTEM

ce	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PB	PM	ZO	ZO
NM	PB	PB	PB	PB	PM	ZO	ZO
NS	PM	PM	PM	PM	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NM	NM	NM	NM
PM	ZO	ZO	NM	NB	NB	NB	NB
PB	ZO	ZO	NM	NB	NB	NB	NB

In order to make a decision, the output fuzzy sets obtained by the implication processes should be combined into a single output variable fuzzy set. This process is called aggregation process. The aggregation method used here is max (maximum). Finally the aggregation output fuzzy set is defuzzified by the

most popular defuzzification method centroid calculation to obtain a single number of output. This process is called defuzzification process. The rule surface of the designed fuzzy control system is shown in Fig. 7.

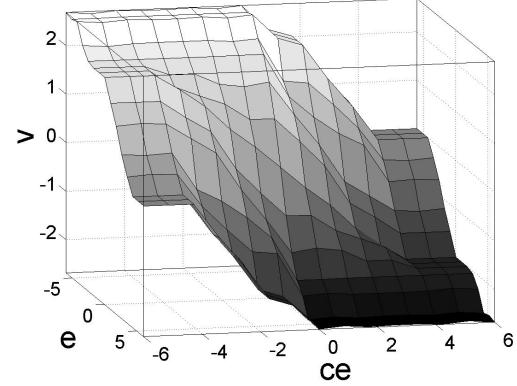


Figure 7. The rule surface of the diesel speed fuzzy control system

In order to improve the performance of the fuzzy controller, we introduce an input proportion factor n and a output proportion factor h , and let $n = |e|/(|e| + |ce|)$, $e = n \times e$, $ce = (1 - n) \times ce$, $h = 400 \times |e|$, and $v = h \times v$. So when the input variable e becomes bigger or smaller, the input variable e and output variable v of the fuzzy controller will become much bigger or smaller. So the fuzzy control system obtains some self-adaptive ability. The designed fuzzy control system of the diesel speed is shown in Fig. 8. The control performance of the fuzzy control system obtained by the means of simulation is shown in Fig. 9.

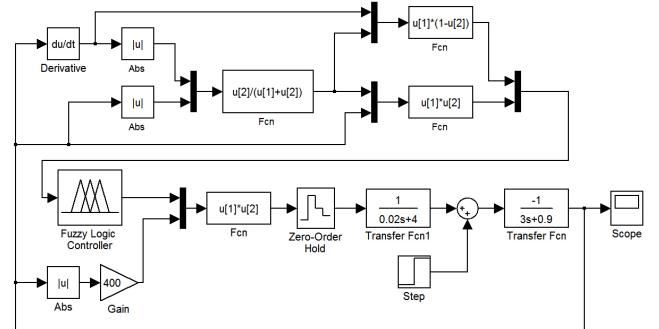


Figure 8. Diesel speed fuzzy control system

IV. CONTROL PERFORMANCE COMPARISON AND APPLICATION

Comparing the performances of the rigid feedback, constant-speed feedback, and fuzzy control system, which are shown in Fig. 3, Fig. 4 and Fig. 8 respectively, we can find the steady speed regulation ratio of the rigid feedback control system is bigger than 12%, the transient speed regulation ratio of the constant-speed feedback exceeds 8%, but in the same conditions the transient speed regulation ratio of the fuzzy control system is smaller than 4% and its steady speed

regulation ratio dose not exceed 2%. So the performance of the fuzzy control system is better than that of the rigid feedback and constant-speed feedback control system.

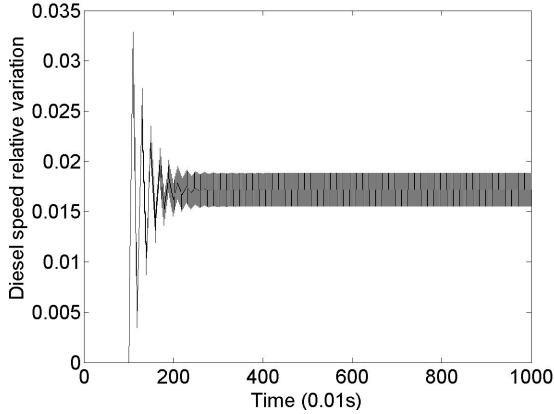


Figure 9. The control performance of the fuzzy control system ($T_a = 3$)

Diesel generator is a very complicated system and many reasons can cause its state to change. So the controller of diesel generator speed should have adaptive ability. For example when diesel parameter T_a changes from 3 to 20 and other control system parameters keep the same, the control performances of constant-speed feedback and fuzzy control system obtained by the means of simulation are shown in Fig. 10 and Fig. 11 respectively, from which we can find the fuzzy control system becomes stable after 2 seconds, but the constant-speed feedback control system is still unstable after 10 seconds. So the fuzzy control system has much more strong adaptive ability than the constant-speed feedback control system.

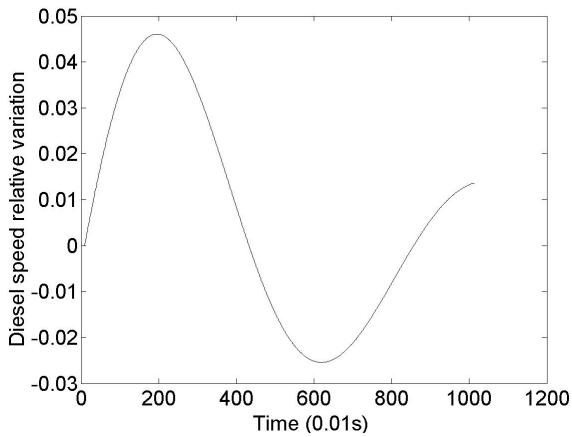


Figure 10. The control performance of constant speed feedback control system ($T_a = 20$)

In application we applied the fuzzy control method presented in this paper to Cummins 250KW diesel generator, which specified speed is 1500 r/min. To provide feedback for the fuzzy logic control loop, an optical sensor is applied. Then the fuzzy control method is used in MSP430F 149 device to control the input voltage of the actuator of the oil pump and

then the diesel speed. According to the experiment results, when the load of the generator changes from 200KW to 100KW, the biggest transient speed of the diesel is 1528 r/min, which transient speed regulation ratio is smaller than 2%, and the biggest steady speed is 1513 r/min, which steady speed regulation ratio is smaller than 1%. So the fuzzy control method presented in this paper is a feasible control method for diesel speed.

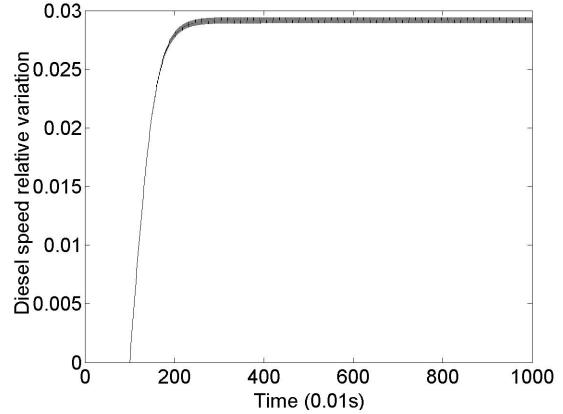


Figure 11. The control performance of fuzzy control system ($T_a = 20$)

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