Synchronous generator fuzzy PID excitation control system

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Abstract. This paper focuses on the design of excitation controller based on fuzzy PID. According to the whole design process, the input and output variables of fuzzy controller are determined. The domain of language variables and membership functions are determined. The selection of quantization factor, average weighted fuzzy method and scale factor in the process of fuzzification; Based on excitation control experience, 49 fuzzy control rules are established.

1. Introduction
Excitation system is an important part of generator. It is a set of system supplying excitation power to synchronous generator. In the operation of power system, it not only controls the terminal voltage of generator, but also controls the reactive power, power factor and current of generator. The results show that the excitation control of a generator is a nonlinear, time-varying system with high response speed. The research of excitation control system has a history of several decades. Various control methods are mature and have their own advantages. A great deal of work has been carried out around the improvement of excitation methods and the innovation of control strategies. The earliest single variable PID regulating mode, from a certain extent, ease the steady-state voltage regulation accuracy and system stability to gain the contradiction of requirements, but it can't effectively improve system dynamic quality and improve the stability of the system, especially when when they need a quick excitation power system damping characteristics, cause the low frequency oscillation. Multivariable PID and at the same time use in achieving the global stability of the local variable feedback at the same time in the suppress low frequency oscillation and to improve the transient stability is have certain effect, there are improvements to the system's robustness and adaptability, but insufficient place is the number of parameters need to be by experiment method to adjust and cooperate with, spend a lot of time, and requires a specific network model and the design of low frequency oscillation space, poor robustness and adaptability, if more than just using the traditional way is certainly cannot reach the purpose of control. Fuzzy control system is a modern intelligent control system. For nonlinear systems, it is based on the description of knowledge in the form of fuzzy mathematics and fuzzy language and the rule inference of fuzzy logic. Good robustness and adaptability. All of these are in line with the characteristics of the excitation system. This paper proposes a synchronous generator excitation control system based on fuzzy controller, which combines fuzzy control with traditional PID synchronous generator excitation control to solve the above excitation control problems, learn from each other and make up for each other, so that the control effect of the system is better, and the adaptability and adjustment ability are stronger.
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2.1. Fuzzy control structure
The fuzzy controller consists of four basic elements:

1) Knowledge base: includes database and rule base, which contains the definition of fuzzy set and fuzzy operator.

2) Reasoning machine: Reasoning is carried out according to the fuzzy input, the control rules in the knowledge base and the reasoning mechanism stored in the database to obtain the fuzzy control value of the output.

3) Fuzzy interface: It will precisely input value fuzzy to a fuzzy value.

4) Defuzzing interface: It can obtain an accurate output value of the output fuzzy set obtained by inference according to the defuzzing method.

2.2. Determine the input and output variable fields
Double input and three output fuzzy controller is adopted. The deviation E and the deviation rate of change are taken as the input of the fuzzy controller, and the three adjustment values of PID are taken as the output. The field definitions of input variables and output variables of the controller are as follows:

\[ E \in \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\} \]
\[ E_c \in \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\} \]
\[ \Delta K_p \in \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\} \]
\[ \Delta K_i \in \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\} \]
\[ \Delta K_d \in \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\} \]

They are divided into 7 grades in the field: NB (negative large), NM (negative medium), NS (negative small), Z (zero), PS (positive small), PM (middle) and PB (above board). The membership functions are all gaussian functions.

Assume that the actual field of \( e \) is written as \([-e_p, e_p]\), the actual field of \( e_c \) is written as \([-e_{cp}, e_{cp}]\), and the field of their corresponding fuzzy state is \([-6, 6]\), so the quantization factors of the two inputs are defined as follows:

\[ G_e = \frac{e_p}{6} \]  
(1)
\[ G_{ec} = \frac{e_{cp}}{6} \]  
(2)

The selection of these two parameters has great influence on the performance of PMSM control system. When \( G_{ec} \) remains unchanged and \( G_e \) is increased, the response speed of the system is accelerated; when \( G_e \) is too large, the overshoot of the system becomes larger, reaching the steady-state transition time side length. When the \( G_{ec} \) is increased while the \( G_e \) remains unchanged, the overregulation of the system is reduced, but the stable speed becomes slower.

From the above analysis, the quantization factor affects the dynamic and static performance of the system, so it is necessary to repeatedly debug the parameters of the quantization factor to make the system performance reach the best.

2.3. Determine fuzzy control rules
Generally, under different \( E \) and \( E_c \), the self-tuning requirements of controlled process on parameters \( \Delta K_p \), \( \Delta K_i \) and \( \Delta K_d \) can be summarized as follows:
1) When \(|E|\) is large, in order to make the system have better fast tracking performance, a large \(\Delta K_p\) and a small \(\Delta K_d\) should be taken. At the same time, in order to avoid a large overshooting of the system response, the integral effect should be limited, usually \(\Delta K_i = 0\).

2) When \(|E|\) is in the medium size, in order to make the system have a small overshoot, \(\Delta K_p\) should be small; In this case, the values of \(\Delta K_p\) and \(\Delta K_d\) should be appropriate.

3) When \(|E|\) is small, in order to make the system have better steady-state performance, \(\Delta K_p\) and \(\Delta K_i\) should be larger. A proper \(\Delta K_d\) prevents oscillations near the equilibrium point.

The core of fuzzy controller design is to summarize the technical knowledge and practical experience of engineering designers and establish an appropriate fuzzy rule table. Based on the above adjustment principles, the adjustment rule table of fuzzy adaptive PID is determined respectively, as shown in Table 1~3:

### Table 1. \(\Delta K_p\) Fuzzy rule table

| \(E_c\) | NB | NM | NS | ZO | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | PB | PB | PM | PM | PS | ZO | ZO |
| NM | PB | PB | PM | PS | PS | ZO | NS |
| NS | PM | PM | PM | PS | ZO | NS | NS |
| ZO | PM | PM | PS | ZO | NS | NM | NM |
| PS | PS | PS | ZO | NS | NS | NM | NM |
| PM | PS | ZO | NS | NM | NM | NM | NB |
| PB | ZO | ZO | NM | NM | NM | NB | NB |

### Table 2. \(\Delta K_i\) Fuzzy rule table

| \(E_c\) | NB | NM | NS | ZO | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NM | NM | NS | ZO | ZO |
| NM | NB | NB | NM | NS | NS | ZO | ZO |
| NS | NB | NM | NS | NS | ZO | PS | PS |
| ZO | NM | NM | NS | ZO | PS | PM | PM |
| PS | NM | NS | ZO | PS | PS | NM | PB |
| PM | ZO | ZO | PS | PS | PM | PB | PB |
| PB | ZO | ZO | PS | PM | PM | PB | PB |

### Table 3. \(\Delta K_d\) Fuzzy rule table

| \(E_c\) | NB | NM | NS | ZO | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | PS | NS | NB | NB | NB | NM | PS |
| NM | PS | NS | NB | NM | NM | NS | ZO |
| NS | ZO | NS | NM | NM | NS | NS | ZO |
| ZO | ZO | NS | NS | NS | NS | NS | ZO |
| PS | ZO | ZO | ZO | ZO | ZO | ZO | ZO |
| PM | PB | NS | PS | PS | PS | PS | PB |
| PB | PB | PM | PM | PM | PS | PS | PB |

### 3. Conclusion

This paper focuses on the design of excitation controller based on fuzzy PID. According to the whole design process, the input and output variables of fuzzy controller are determined. The domain of
language variables and membership functions are determined. The selection of quantization factor, average weighted fuzzy method and scale factor in the process of fuzzification; Based on excitation control experience, 49 fuzzy control rules are established.

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