Application of Fuzzy-PI-based Voltage Control in STATCOM

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Abstract. Distribution static synchronous compensator (STATCOM) can effectively solve dynamic voltage quality problems in power distribution network, such as voltage fluctuation and flicker, voltage drop, etc. A Fuzzy -PI-based voltage control strategy is proposed in the paper aiming at the requirements of the power distribution network on load access point transient voltage. The simulation results and field data show that Fuzzy-PI-based voltage control strategy in the paper has excellent robustness and fast response speed compared with traditional PI controller, which can meet the requirements of STATCOM voltage control.

Keywords: Distribution static synchronous compensator; voltage quality; Fuzzy-PI; voltage control.

1. Introduction
Voltage fluctuation and flicker, voltage drop and other dynamic voltage quality problems in power distribution network leads to adverse influence on power users and the grid itself [1]. Therefore, it is necessary to adopt reactive power compensation device to control. Traditional reactive power compensation devices can not meet the control requirements of dynamic voltage quality easily due to low response speed, narrow operating range, etc. STATCOM devices based on power electronics devices can comprehensively solve various power quality problems in the power distribution network in recent years, and they have attracted much attention in the field of power quality control [2].

When STATCOM is used for improving the dynamic voltage quality of the power distribution network, it requires fast response speed [3]. The improvement of STATCOM response speed is restricted by the following two factors: firstly, the connection reactance current cannot be mutated; secondly, there is coupling effect of active current and reactive current in the dynamic process. Therefore, after the topology of the STATCOM main circuit and its parameters are determined, the controller is the key factor affecting the response speed of STATCOM device, and the control strategy adopted in the controller is crucial [4].

2. Ease of Use
Fuzzy control theory is applied to the adjustment of PI controller parameters in view of the shortcomings of traditional PI controller. The method is applied to the STATCOM voltage control system. The basic idea is shown as follows: fuzzy control is combined with traditional PI control, and fuzzy control method is adopted for adjusting PI parameters automatically according to system performance requirements, thereby achieving good static and dynamic performance of STATCOM control system.
The schematic diagram of Fuzzy-PI controller is shown in Fig 1.

![Fuzzy-PI controller diagram](image)

**Fig. 1 Schematic diagram of fuzzy-PI controller**

In figure 1, \( U^*_{\text{pcc}} \) refers to voltage reference value of the public connection point, \( U_{\text{pcc}} \) refers to actual voltage value, \( \Delta K_p \) and \( \Delta K_i \) respectively refers to changes of proportional coefficient and integral coefficient of PI controller. Deviation \( e \) and deviation change rate \( \Delta e \) are input into Fuzzy-PI controller (namely \( de/dt \)), \( \Delta e = \Delta(U^*_{\text{pcc}} - U_{\text{pcc}}) \), fuzzy reasoning is applied for blurring operation. \( \Delta K_p \) and \( \Delta K_i \) at the time pint can be obtained, thereby realizing the optimal adjustment of PI parameters.

3. Design of Fuzzy-PI controller

3.1. Parameter presetting

The initial parameters \( K^*_p \) and \( K^*_i \) of Fuzzy-PI controller are solved by Ziegler-Nichols method. The steps are shown as follows:

- Set \( K^*_p = K^*_i = 0 \).
- Gradually increase \( K^*_p \) until system oscillation, and record value \( K_c \) and oscillation cycle \( T_i \) at the critical state \( K^*_p \).
- Determine the initial value parameter \( K^*_p = 0.45 \times K_c, \ K^*_i = 0.83 \times T_i \) of the controller.

3.2. Obfuscation of input/output variables

The input and output variables of a fuzzy controller are both precise, while fuzzy reasoning is carried out for fuzzy quantities. Therefore, the controller should firstly make fuzzy processing of input variables. The language values of input and output variables are divided into 7 language values by the Fuzzy-PI controller designed in the paper \{ NB, NM, NS, ZO, PS, PM, PB \}, wherein NB, NM, NS, ZO, PS, PM, PB respectively represent negative big, negative medium, negative small, zero, positive small, positive medium and positive big values. The fuzzification process is illustrated by the input deviation as follows:

- The real field deviation \( e \) is transformed into the discrete field \( E = \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\} \).
- 7 fuzzy sets \( NB, NM, NS, ZO, PS, PM \) and \( PB \) are defined aiming at \( E \).
- Trig function is adopted as membership function, and the membership degree of each fuzzy set is determined.
3.3. Determination and fuzzy reasoning of parameter tuning rule

Parameter tuning rule is shown as follows:

- When $|e|$ is large, namely $e \in \{NB, PB\}$, it should be ensured that $\Delta K_p$ is large in order to achieve better rapid tracking performance for the system. Meanwhile, $\Delta K_i$ should be resisted in order to avoid larger overshoot of system response, and $\Delta K_i = 0$ is generally adopted.
- When $|e|$ is medium, namely $e \in \{NM, PM\}$, $\Delta K_p$ should be small, and $\Delta K_i$ value can be suitable increased in order to avoid large overshoot of the system.
- When $|e|$ is small, namely $e \in \{NS,0, PS\}$, $\Delta K_p$ should be further reduced in order to stabilize the system as soon as possible, $\Delta K_i$ value should be suitable increased, which can be increased with the decrease of $|e|$, thereby reducing steady error of the system, and improving the control precision.
- Factors of $\Delta e$ are taken into account at the same time. When the change direction of $e$ is the same as the change direction of $\Delta e$, the output is changed to the direction deviated from the stable value, $\Delta K_p$ should be suitable increased, otherwise $\Delta K_p$ should be suitable decreased.

Fuzzy reasoning is applied for fuzzy calculation according to the above tuning rule, thereby obtaining the fuzzy quantity of $\Delta K_p$ and $\Delta K_i$.

| Fuzzy set | NB | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
|-----------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Membership | NB | 0.7 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|           | NM | 0.2 | 0.8 | 1.0 | 0.8 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|           | NS | 0.0 | 0.2 | 0.8 | 1.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|           | ZO | 0.0 | 0.0 | 0.0 | 0.5 | 1.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
|           | PS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|           | PM | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.8 | 1.0 | 0.8 |
|           | PB | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Tab. 2 $\Delta K_p$ control rule

| $\Delta e$ | $\Delta K_p$ | NB | NM | NS | ZO | PS | PM | PB |
|------------|--------------|----|----|----|----|----|----|----|
| NB         | PB | NB | PB | NB | PM | PS | PS | 0  |
| NM         | PB | PB | NM | PB | PM | PS | PM | 0  |
| NS         | PM | PM | NS | PM | PS | 0  | NS | NM |
| ZO         | PM | PS | 0  | 0  | NS | NM | NM | NM |
| PS         | PS | PS | 0  | 0  | NS | NS | NM | NM |
| PM         | 0  | 0  | NS | NM | NM | NM | NM | PB |
| PB         | 0  | NS | NS | NM | NM | NM | PB | NB |
### Tab.3 ΔKi control rule

| ΔeΔK<sub>i</sub> | NB | NM | NS | ZO | PS | PM | PB |
|------------------|----|----|----|----|----|----|----|
| NB               | 0  | 0  | NB | NM | NM | 0  | 0  |
| NM               | 0  | 0  | NM | NM | NS | 0  | 0  |
| NS               | 0  | 0  | NS | NS | 0  | 0  | 0  |
| ZO               | 0  | 0  | NS | NM | PS | 0  | 0  |
| PS               | 0  | 0  | 0  | PS | PS | 0  | 0  |
| PM               | 0  | 0  | PS | PM | PM | 0  | 0  |
| PB               | 0  | 0  | NS | PM | PB | 0  | 0  |

#### 3.4. Output deblurring

Maximum membership method is adopted for obtaining accurate value of ΔK<sub>p</sub> and ΔK<sub>i</sub> aiming at the fuzzy quantity of ΔK<sub>p</sub> and ΔK<sub>i</sub> obtained through fuzzy reasoning.

#### 3.5. Determination of control parameters

Maximum adjustment parameters ΔK<sub>p</sub> and ΔK<sub>i</sub> of Fuzzy-PI controller can be obtained according to formula (1):

\[
K_p = K_p^* + \Delta K_p, \quad K_i = K_i^* + \Delta K_i
\]  

#### 4. Analysis on test results

Fuzzy-PI algorithm and traditional PI algorithm are respectively simulated in the SIMLINK simulation environment of MATLAB in order to verify the effectiveness of the algorithm. Step response curve shows that Fuzzy-PI algorithm has higher response speed and robustness compared with traditional PI algorithm.

![Fig.2 PI step response](image1)

![Fig.3 Fuzzy-PI step response](image2)

Fuzzy-PI algorithm and PI algorithm are transplanted to STATCOM voltage closed loop control in order to further verify the effectiveness of the algorithm. It can be seen from table IV that Fuzzy - PI algorithm shortens the response time by nearly 16ms than PI algorithm in the process of stepping 35 kV bus voltage from 35.3 kV to 36.2 kV, the response time of Fuzzy-PI algorithm is only 20.015ms.
compared with traditional PI algorithm during the process of stepping bus voltage from 36.2kV to 36.8 kV based on the site actual application of STATCOM (Ningxia Pingluo Photovoltaic Power Station) and related data collection, thereby meeting the requirements of state grid for dynamic response of STATCOM. Then, the real-time voltage curve recorded by the central control system shows that the operations of traditional PI algorithm becomes stable after several oscillations during voltage stepping, and Fuzzy-PI algorithm does not have oscillation phenomenon, thereby it has higher robustness.

### Tab.4 Thereby it has higher robustness

| Control algorithm | Set reference step change | SVG compensation capacity (Mvar) | SVG response time (ms) |
|-------------------|--------------------------|---------------------------------|-----------------------|
| Traditional pi algorithm | 35.3kV～36.2kV | 4.712 | 36.017 |
| | 36.2kV～36.8kV | 5.164 | 36.015 |
| Fuzzy-PI algorithm | 35.3kV～36.2kV | 4.617 | 20.017 |
| | 36.2kV～36.8kV | 5.063 | 20.015 |

5. Conclusion

Fuzzy control is applied to STATCOM voltage closed-loop control in the paper. The design and implementation process of Fuzzy-PI voltage controller are introduced in details. Simulation results and field data show that the advantages of fuzzy control and PI control are combined in the voltage control algorithm proposed in the paper, and it has high response speed and robustness, which can improve the dynamic performance of the system, and it is an ideal control method.

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