Power System Stabilizer with Variable Fuzzy Logic Control Signal

Member Satoshi Nanjo (Tokai University)
Member Yoshibumi Mizutani (Tokai University)
Member Kazuto Yukita (Tokai University)
Member Takatugu Okabe (Electric Power Development Co. Ltd.)
Nonmember Yoichiro Kinoshita (The Kaihatsu Computing Service Center Ltd.)

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1. INTRODUCTION

This paper presents a new fuzzy control method to improve the stability and robustness of power system under both of the large and small disturbances. The variable gain control signal corresponding to the operating conditions of power system is introduced to the proposed method. The effectiveness of the proposed method is demonstrated by the computer simulation results.

2. MODEL SYSTEM

Consider the single machine connected to an infinite bus through a double transmission line as shown in Fig. 1(a) and the synchronous machine is equipped with an automatic voltage regulator (AVR) in Fig. 1(b) and a governor (GOV) in Fig. 1(c).

3. PROPOSED METHOD

Fig. 2 shows the proposed method that the variable gain is introduced to the phase plane type fuzzy logic control in [1].

The approximate acceleration $Z_a(k)$ and the approximate speed deviation $Z_s(k)$ are calculated by the filtering blocks in Fig. 3.

The operating point $P(k)$ in Fig. 2(a) is given by

$$ P(k) = D(k)/\dot{\theta}(k) $$

where $D(k)$ is the magnitude.

The direction and gain of control signal are determined by the membership functions of $\dot{\theta}$ in Fig. 2(b) and $D$ in Fig. 2(c), respectively.

In order to improve the stability and robustness of power system under both of the large and small disturbances, the proposed method introduces the following two rules.

1. To increase the region of the deceleration control with the value of disturbance by the shift of switching line (SL) in Fig. 2(a), the tuning rule of SL introduced to the membership function of $\dot{\theta}$ is given by

$$ \theta(k) = \cos^{-1}\{Z_s(k)/D(k)\} $$

where $\dot{\theta}(k)$ is the phase angle, $D(k)$ is the magnitude.

The approximate acceleration $Z_a(k)$ and the approximate speed deviation $Z_s(k)$ are calculated by the filtering blocks in Fig. 3.

The operating point $P(k)$ in Fig. 2(a) is given by

$$ P(k) = D(k)/\dot{\theta}(k) $$

(1)

$$ \theta(k) = \cos^{-1}\{Z_s(k)/D(k)\} $$

(2)

where, $0 \leq \dot{\theta}(k) \leq \pi$

Table 1. System constants

<table>
<thead>
<tr>
<th>System constants</th>
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</thead>
<tbody>
<tr>
<td>Generator: $M=7.2,[\text{s}], V_{to}=1.0,[\text{pu}], D=0.0053,[\text{pu}], X_{s}=1.62,[\text{pu}], X_{p}=0.25,[\text{pu}], X_{d}=0.25,[\text{pu}], X_{q}=1.6,[\text{pu}], V_{to}=1.0,[\text{pu}], f_{o}=377.0,[\text{rad/s}], V_{b}=1.0,[\text{pu}], AVR: K_{a}=200.0, T_{a}=0.05,[\text{s}], T_{f}=1.25,[\text{s}], K_{f}=0.07, E_{f_{max}}=7.3,[\text{pu}], U_{f}=0.1,[\text{pu}], GOV: K_{a}=0.05,[\text{pu}], T_{a}=0.2,[\text{s}], T_{r}=2.0,[\text{s}], P_{max}=1.05,[\text{pu}], P_{min}=1.0,[\text{pu}], Filtering Blocks: T_{r}=5.0,[\text{s}], W=3.1</td>
</tr>
</tbody>
</table>

FIG. 1. MODEL SYSTEM

FIG. 2. PROPOSED FUZZY LOGIC CONTROL METHOD

FIG. 3. FILTERING BLOCKS

T. IEE Japan, Vol. 117-B, No. 6, '97
(2) To tune the gain of the control signal with the value of disturbance by the variable parameter $\alpha_4 / D(k)$, the grade of the membership function of $D$ is given by

$$
\begin{cases}
\text{if } 0 \leq \mu_D(k) < 1 & \Rightarrow \mu_D(k) = D(k)/(\alpha_4 / D(k)) \\
\text{if } \mu_D(k) \geq 1 & \Rightarrow \mu_D(k) = 1
\end{cases}
$$

The stabilizing signal $U_c(k)$ of proposed method is calculated by the following weighted average method of defuzzification using the membership functions of $\theta$ and $D$.

$$U_c(k) = \frac{\mu_D(k) - \mu_D(k)}{\mu_D(k) + \mu_D(k)} U_m$$

where, $U_m$ is the maximum value of the control signal.

4. PARAMETER SETTING

The four parameters are set by the following procedures.

1) $\alpha_1$ is set by minimizing the performance index $J_1$ of Eq. 5.
2) $\alpha_2$ is set by minimizing the performance index $J_2$ of Eq. 6.
3) $\alpha_3$ is set by minimizing the sum of $J_1$ and $J_2$.
4) $\alpha_4$ is set by minimizing $J_2$.
5) $\alpha_5$ is set by minimizing $J_2$ when $X_j$ shown in Fig. 1(a) is the stability limit repeatedly.

$$J_1 = \sum [W \times (Z_a(k)^2 + U_c(k)^2) (kT)^2]$$

$$J_2 = \sum [(Z_a(k)^2 + U_c(k)^2) (kT)^2]$$

where, $J_1$ is calculated at the small disturbance and $J_2$ is calculated at the large disturbance in Appendix 1.

$W$ is the weight factor.

Table 2. Tuning parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proposed method</th>
<th>Conventional method</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_1$</td>
<td>0.95</td>
<td>0.20</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>39.5</td>
<td>10.5</td>
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<tr>
<td>$\alpha_3$</td>
<td>24.0</td>
<td>0.35</td>
</tr>
<tr>
<td>$\alpha_4$</td>
<td>5.00</td>
<td>0.40</td>
</tr>
<tr>
<td>$Z_p$</td>
<td>-</td>
<td>0.45</td>
</tr>
</tbody>
</table>

5. SIMULATION RESULTS

For the simulation of this paper, Figs. 1 and 1(a) are used as a model system and the system constants respectively.

Fig. 4 shows the responses of the large disturbance for $1.44 \times X_j$. Figs. (a) and (b) show the proposed method and the conventional method in [1], respectively. The proposed method gives higher robustness than the conventional method over the stability limit regarding to the increase of $X_j$. Fig. 5 shows the responses of the small disturbance. The proposed method gives the good performance under both of the large and small disturbances.

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REFERENCES


APPENDICES

Appendix I : Used disturbances on this study
Large : A three phase to ground fault at the point "f" of Fig. 1(a) and the faulted one line circuit is opened after 0.1[s].
Small : The mechanical output power $P_m$ of the power plant is decreased by 0.05[pu].

Appendix II : Conventional method

The five parameters are set by [1] and $\alpha_5$ is set by the procedure 5 of the chapter 4.

$$Z_a = Z_s + Z_{ss}$$

where, $Z_{ss} = \alpha_1 Z_p$ for $|Z_p| \geq Z_{pmin}$

$$Z_{ss} = 0 \quad \text{for } |Z_p| < Z_{pmin}$$

app. Fig. 1. Conventional method

Satoshi Nanjo (Member) was born March 1st, 1972. He graduated from Tokai University in 1995. He is attending master course at the same University. He is studying stability control based on the fuzzy logic for synchronous generator and high speed phase shifter.

Yoshibumi Mizutani (Member) see Vol. 116-B, No. 3, p. 367
Kazuto Yukita (Member) see Vol. 116-B, No. 3, p. 367
Takatugu Okabe (Member) see Vol. 116-B, No. 3, p. 291
Yoichiro Kinoshita (Nonmember) was born December 31, 1962. He received the B.S. degree in engineering from Chuo University in 1986. In 1991, he joined The Kaihatsu Computing Service Center Ltd. He is working for the development of power system software.