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Coordination of Excitation and Governing Control Based on Fuzzy Logic

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Abstract: In deregulated power systems, competition could push the system near its security limit. The issue of power system stability is becoming more crucial. The excitation and governing controls of generator play an important role in improving the dynamic and transient stability of power system. Typically the excitation control and governing control are designed independently. In this paper, we present a fuzzy logic based method for the excitation control and governing control. Fuzzy logic is applied to generate two compensating signals to modify the controls during system disturbances. A single machine to infinite bus system is applied in simulation. The oscillation of internal generator angles is observed to indicate the good performance of proposed control scheme.

Key words: Power system, Transient stability, Fuzzy logic, Excitation and governing control.

1. Introduction

Power system stability issue has been studied widely. Many significant contributions have been made, not only in the aspects of analyzing and explaining the dynamic phenomena, but also in the efforts of improving the stability of transmission systems. Among these techniques, generator control is one of the most widely applied in the power industry. This typically includes governing and excitation control. Most attention is directed toward the excitation control. Most of excitation controls are based on SISO PID control, MIMO linear control, optimal linear and non-linear control, and intelligent control, such as applications of neural network and fuzzy logic. [1-12].

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are difficult and sometime even impossible to be described using traditional methods. One example in power system is to describe the severeness of power system disturbances accurately. Fuzzy set theory has been widely used in the control area with some application to power systems. A simple fuzzy control is built up by a group of rules based on the human knowledge of system behavior.

In power engineering area, fuzzy set theory is applied in power system control, planning and some other aspects. Fuzzy logic has also been applied to design power system stabilizers[3-12]. Governing system behavior is neglected in the design of excitation control. Part of the reason is the slow response of governing systems compared with the exciting system. However proper control of governing system is helpful in damping system oscillation and improving the transient stability.

Here we present a coordination of governing control and excitation control using fuzzy logic compensate their control inputs during faults. The speed (ω), accelerating speed (P_m-P_e) and the terminal voltage (V_t) of generator are observed to characterize the severeness of oscillation.

In this paper, the design of fuzzy logic is applied to a single machine to infinite bus system. A 3-phase fault is used as an example of system disturbances. SIMULINK simulation model is built to study the dynamic behavior of synchronous machine and the performance of proposed controller. The simulation results are demonstrated in the followed section.

2. Fuzzy Control Design

The basic dynamic behavior of a generator can be shown using a simple single machine to infinite bus system. In our study, we design the control scheme for the single generator. The governing control is a traditional PID control, which is similar to IEEE type 1 model. The excitation control is a linear optimal control

2.1 Design of linear optimal excitation control (LOEC)[1]

LOEC is an application of modern optimal control theory in power system. The output power (P_e), speed (ω), terminal voltage (V_t) and the exciting field voltage (E_{fd}) of synchronous machine are introduced as feedbacks in the excitation control. The LOEC is designed by linearizing the nonlinear system at an operating point. The LOEC block diagram built for SIMULINK is shown in Fig. 1. Coefficients K obtained from optimal control method will be modified by high gain coefficients to improve the performance. Here we pick K as

$$[\, K_v, K_P, K_\omega, K_{Ef} \,] = [80, 7.5, 1000, 1].$$

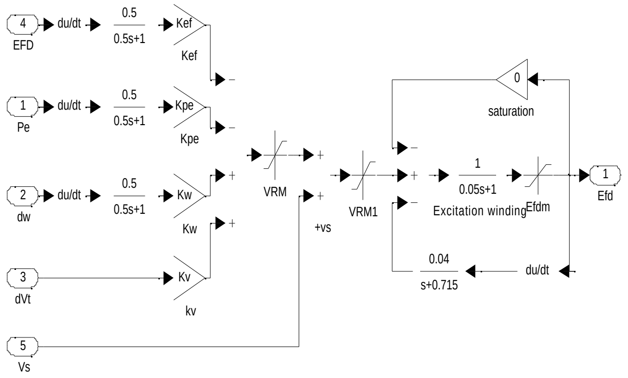


Fig.1 LOEC Block Diagram

The input V_s is a compensating signal that will be generated by fuzzy logic.

2.2 Governing control model

A traditional PID controller is applied in the governing control. Type1 of power frequency electric-hydraulic governing control system is used in simulation. Its block diagram is shown in Fig.2. The parameters are assigned values as shown in Table 1.

KD	KP	TD(s)	TI(s)	TE(s)	TS	TO(s)
20	1	1.0	1.0	0.4	0.5	0.3

Table 1. Parameters of Governing System

The input U_s is a compensating signal that will be generated by fuzzy logic.

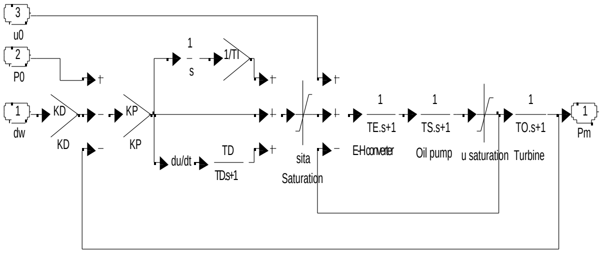


Fig.2 PFEH Speed Control Block Diagram

Typically excitation system is a fast response system. The time constant is small. The governing system is a relatively slow response system because of the slow reaction of mechanic operation of oil pump, volume of reheating pipes and turbine machine.

2.3 Design of fuzzy logic compensation[3,13]

One objective of generator control is to keep the generator operating after some unexpected system faults. Two performance indices are concerned. One is the oscillating time, or the system damping. The faster, the better. The other is the system transfer capability. The more power transferred, the better.

To demonstrate this objective, we are using the simplest system.

In a single machine to infinite bus system, the power output of generator can be expressed as

$$P_e = \frac{EqVs}{X_{d\Sigma}} \sin\delta$$

When there is fault in the transmission line, as shown in Fig. 3. The machine will run along the curve II during the fault period. When the fault disappears, the machine will run along curve I. Area A is the accelerating energy and Area B is the decelerating energy. To damp system as soon as possible, Area A and B must become smaller. Two possible measures will be taken. One is reducing the mechanic power P_m input, the other is increase the electric power P_e output.

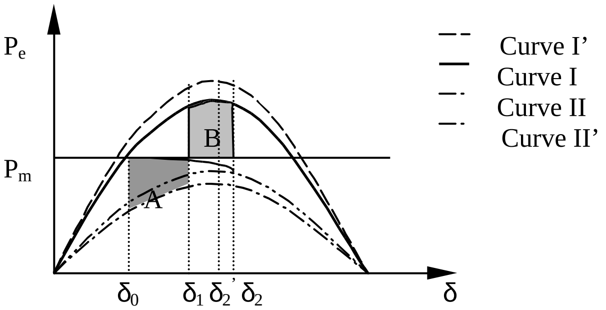


Fig.3 Equal Area Rule of Generator Oscillation in First Swing

The expected running curve is Curve II' during the fault period and Curve I' after fault. Then the maximum internal angle is decreased from δ_2 to δ_2'. This operation can be achieved by increase the voltage and decrease P_m.

The behavior after the first swing will follow same argument; increasing the voltage and decreasing the mechanic power when machine is in acceleration, decreasing the voltage and increasing the mechanic power when machine is in deceleration. Simply the argument can be shown in diagram in Fig.4 and 5.

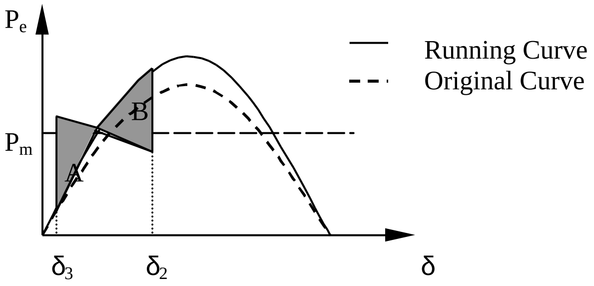


Fig.4 Expected Dynamic Behavior when δ increases

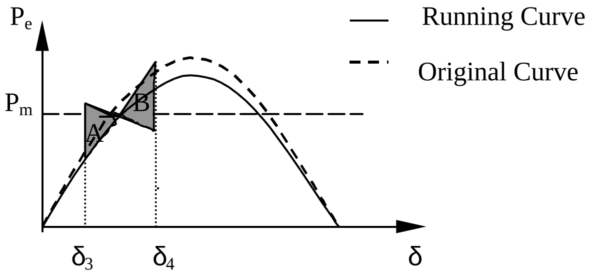


Fig.5 Expected Dynamic Behavior when δ decreases

Considering the slow reaction of governing system, two compensating signals U_s and V_s are generated by fuzzy logic loop. There are three blocks in the fuzzy logic module, fuzzification of input variables, fuzzy rules and defuzzification to generate outputs. The fuzzy logic module can be shown as in Fig.6.

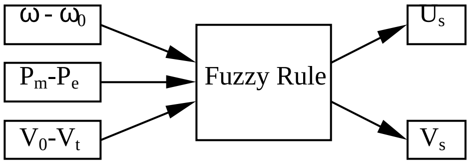


Fig.6 Block Diagram of Fuzzy Logic Module

Fuzzification of inputs is shown in Fig. 7 to 9. Defuzzification is shown in Fig. 10 and 11.

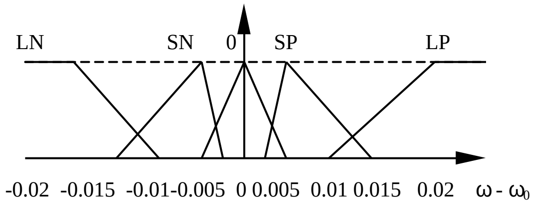


Fig.7 Fuzzification of ω - ω_0

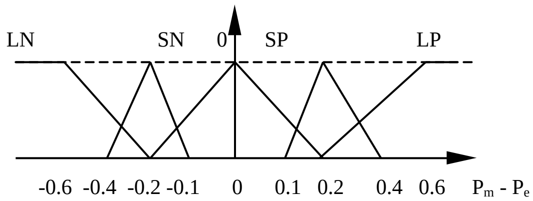


Fig.8 Fuzzification of P_m - P_e

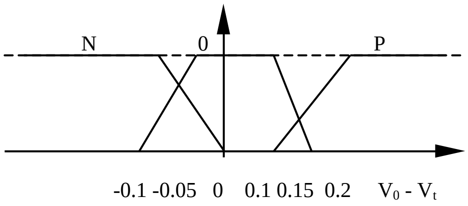


Fig.9 Fuzzification of V_0 - V_t

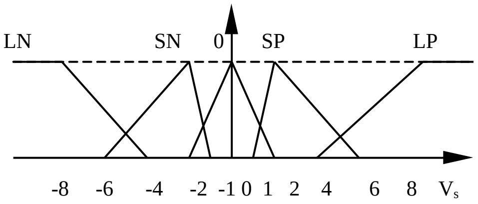


Fig.10 Defuzzification of V_s

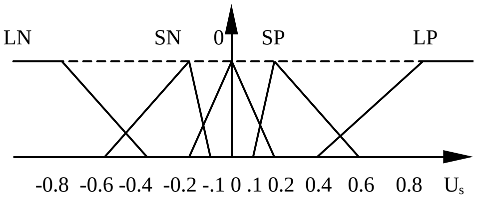


Fig.11 Defuzzification of U_s

The fuzzy logic rule is shown in Table 2 to 3.

dω\dP	LN	SN	0	SP	LP
LN	SN	SN	SN	0	SP
SN	SN	SN	0	0	SP
0	SN	0	0	0	SP
SP	SN	0	0	SP	SP
LP	SN	0	SP	SP	SP

Table 2. Fuzzy Logic Rules for U_S when V_0 - V_t is not P

dω\dP	LN	SN	0	SP	LP
LN	LN	LN	LN	LN	SN
SN	SN	SN	0	0	0
0	SN	0	0	0	SP
SP	LP	LP	LP	LP	LP
LP	LP	LP	LP	LP	LP

Table 3. Fuzzy Logic Rules for V_S when V_0 - V_t is not P

When V_0 - V_t is P, then U_s is always LN and V_s is always LP except when dω and dP are 0s. Here dω is denoted as ω - ω_0, and dP is denoted as P_m-P_e.

3. Built System in Simulation[13]

The proposed design scheme is implemented in SIMULINK. We tested the design in the single machine to infinite bus through a double lines system.

The generator and system parameters are given in Table 4.

X_d	X_q	X_d'	X_q'	X_2	T_{do}'
1.2	1.2	0.2	0.2	0.2	6.0
T_{qo}'	H	D	X_T	X_L	P_N
0.6	10	2	0.2	1.6	1.0

Table 4. Parameters of Model System

Here the symbols follow the standard representation. The voltage of infinite bus is set as V = 1.0.

The 4-order synchronous machine model is applied in the simulation. The SIMULINK diagram is shown as Fig. 12.

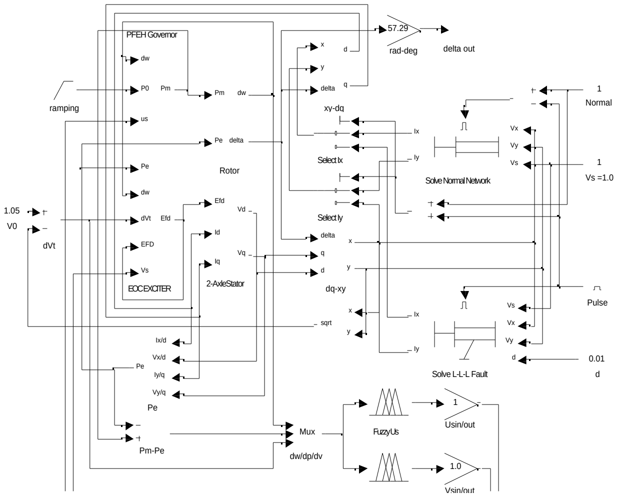


Fig.12 Diagram of Simulated System in SIMULINK

4. Simulation Results

In the simulation, we want to obtain a group of results that will support our design. First we looked at the performance of the controllers with compensations. In this case, we run the generator at initial point, power output P_0 = 0.6 and terminal voltage V_t = 1.03. Three-phase fault occurs at t = 2.0 second at the beginning of one line and last for 0.2 second. The compensating signal U_s for governor generated by fuzzy logic block is shown in Fig.13. The generated compensating signal V_s for LOEC is shown in Fig.14. By comparing the oscillation of internal angle δ of generator in 2 cases, with and without fuzzy logic compensation, as shown in Fig.15, the oscillation of δ in the case with compensation is damped out faster than that without compensation.

Fig.13 Vs Compensation

Fig.14 Vs Compensation

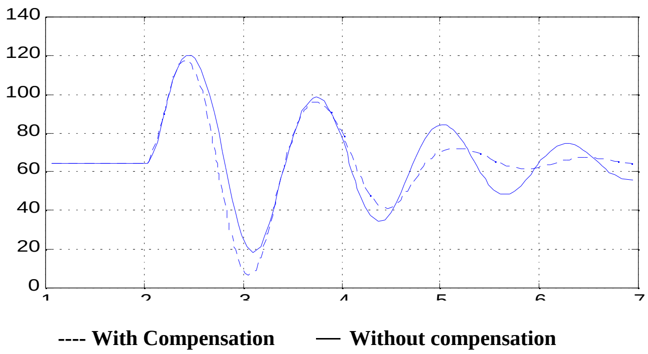


Fig.15 Comparison of Oscillation of Internal Angle of Generator

Second, we compared the transient stability of the transmission line. Three-phase fault in the beginning of the transmission line is used as an example. Table 5 shows us about 4.55% increase of the transient stability.

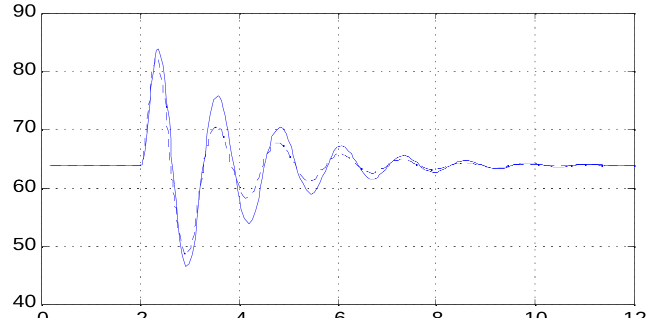
Case	Maximum P output
No Compensation	0.66
Compensation	0.69

Table 5. Comparison of Maximum Transfer Capability

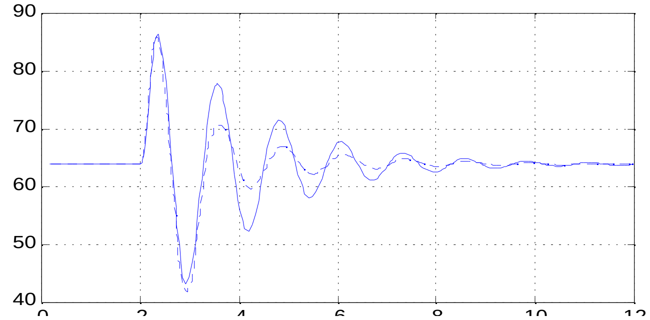
The benefits came from the decrease of mechanical power and increase of the voltage after fault disappeared in the first swing.

Third, the robustness of compensated control is studied in simulation. The severeness of system faults is simulated by the faults at different positions in the transmission line. We still use the same initial operating point and same fault setting as described in the above. The faults at the beginning, in the middle and at the end of one transmission line are studied.

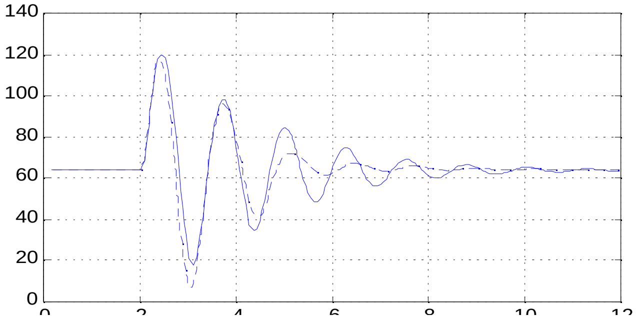
Fig. 16 to 18 show the comparison of the oscillation of internal angle δ of generator in three cases respectively.



---- With Compensation —— Without compensation
Fig.16 Comparison of Oscillation of Internal Angle of Generator With Fault at the End of Transmission Line



---- With Compensation —— Without compensation
Fig.17 Comparison of Oscillation of Internal Angle of Generator With Fault in the Middle of Transmission Line



---- With Compensation —— Without compensation
Fig.18 Comparison of Oscillation of Internal Angle of Generator With Fault at the Beginning of Transmission Line

It can be observed that the proposed compensation is robust in different system faults. In serious and slight system faults cases, the compensations help the original controls to damp the system oscillation.

Also some other cases were simulated to check the performance of proposed compensating, including the single line to ground, double lines to ground and line to line faults, load jumps. When the disturbances are trivial, which won't cause large oscillation, as designed, there are no compensating outputs. LOEC display very good performance in damping the small oscillation.

The cases with only one compensating output are also studied. When only the output for exciting control is added, the control performance is better than that without compensation except the first swing. But when only the output for governing control is added, the first swing is better but those after first swings are worse than the oscillation in the case without compensation. The proposed fuzzy logic automatically coordinates the behavior of the 2 compensations.

5. Conclusion

The generator controls are investigated in a single machine to infinite bus system. By analyzing the dynamic behavior of synchronous machine, two compensating variables are introduced based on the fuzzy logic. Since both governing and exciting controls are compensated, the proposed fuzzy logic coordinates the behaviors of two controls. System oscillation, which is caused by some unexpected faults, is shown to be quickly damped.

The robustness of the proposed control is studied. The compensated generator controls display good performance for different system disturbances.

The system transfer capability is increased. In our case, the transient transfer limit increased by 4.55%.

Clearly the proposed design is not a nonlinear optimal control. Here we introduce a fuzzy logic compensation scheme is to improve the original generator control.

Further work in self-learning fuzzy logic design is useful in modifying the fuzzy logic rules. The self-learning process can make the fuzzy logic rules more suitable for specific systems.

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