2001년도 대한전기학회 전력기술부문회 춘계학술대회 논문집 (2001.5.11)

부하 주파수 제어를 위한 퍼지 로직 기반 확장 적분 제어

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Fuzzy Logic Based Extended Integral Control for Load Frequency Control

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Abstract - This study presents an effective variable forgetting factor method based on fuzzy logic to suppress frequency droop in extended integral load frequency control. The performance of the extended integral control is greatly dependent on the decaying factor. For an optimal or near optimal performance, it is necessary that the decaying factor as well as the feedback gains should be changed very quickly in response to changes in the system dynamics. However, because of its time-varing characteristic, the optimal decaying factor is difficult to be selected analytically. By adopting fuzzy set theory, the decaying factor can be determined quickly to respond to the variation of the feedback signals. This study builds a fuzzy rule base with use of the change of frequency and its rate as inputs. The computer simulation has been conducted for the single machine system. The simulation results show that the proposed fuzzy logic based controller yields more improved control performance than the conventional PI controller.

1. Introduction

Many investigations have been done in the area of LFC(Load Frequency Control). Among various types of load frequency controller, the PI controller is most widely applied to speed-governor system for LFC scheme[8,9]. An advantage of the PI control technique is to reduce the steady-state error to zero by feeding the errors in the past forward to the plant. However, the inherent singular characteristics of speed-governor system have a great influence on LFC behavior, which makes it more difficult to maintain the required frequency accuracy. It is well known that the conventional PI LFC scheme does not yield adequate control performance with consideration of the singularities of speed-governor such as rate limits on valve position and GRC(Generation Rate Constraint). The speed-governor system should be operated within the restricted control range of feedback gains due to the system instability. Moreover, in the deregulated environments, frequent on-off controls of large capacity units may bring about large amount of power disturbances, which has not been experienced before. This requires the modification of the conventional LFC scheme, and Moon et al.[1,2,3] have suggested a new LFC scheme adopting a modified PID control based on optimal tracking approach. However, since the conventional PI controller with fixed gains has been designed at nominal operating conditions, it failed to provide best control performance over a wide range of operating conditions. In order to overcome this drawback, Moon et al.[4] have suggested a new LFC scheme adopting an extended PI control. The performance of the extended integral control is greatly dependent on the decaying factor. For an optimal or near optimal performance, it is necessary that the decaying factor as well as the feedback gains should be changed very quickly in response to changes in the system dynamics. However, because of the inherent characteristics of the changing loads and the system non-linearities such as GRC, the decaying factor and the feedback gains are difficult to be selected analytically and quickly in real time. In the earlier work[4], the decaying factor was selected intuitively and heuristically in proportion to the degree of deviation of feedback signals. AI-based method is an alternative solution which is a technique commonly used in designing controllers for nonlinear systems. AI-based methods have many advantages to control nonlinear system since they have an approximation ability using nonlinear mappings. Generally, they provide a model-free description of control systems and do not require model identification.

This study presents an application of fuzzy logic based method to determine the optimal parameters for the extended integral control scheme. Under the environment that the system changes over a wide range of operating condition, the extended integral control scheme can provide satisfactory control performance. It is an important point that the time-varing decaying factor in the extended integral control should be changed in accordance with the degree of frequency deviation. Because of its time-varing characteristic, the optimal decaying factor is difficult to be selected analytically. By adopting fuzzy set theory, the decaying factor can be determined quickly to respond to the variation of the feedback signals. The computer simulation has been conducted for the single machine system with use of Fuzzy Logic Toolbox and Simulink in MATLAB 5.3. The simulation results show that the proposed fuzzy logic based controller yields more improved control performance than the conventional PI controller.

2. Extended Integral Control Scheme

The PI control technique perfectly reduces the steady-state error to zero. However, in some control problems, some disturbances resulting from the PI control are obstacles for other control purposes. For example, in the LFC system of power systems, the PI control causes some disturbances for AGC. The integration of the frequency error in the past remains forever affecting the steady state operation points after the system state has settled down.

In order to remove the above undesirable effects, an extended integral control has been developed for the PI control of the speed governor[4]. The convolution integration concept is introduced by substituting convolution integral for general integral term in PI control scheme. The extended integral control scheme is shown in Fig. 1

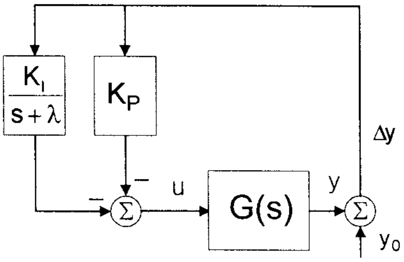


Fig. 1 Extended Integral Control

In the convolution integral control scheme, an exponential decaying function is chosen as a convolution integral type as follows:

$$h(t) = e^{-\lambda t}u(t) \tag{1}$$

It is noted that the key idea of the extended integral control is using a decaying factor to reduce the effects of the error in the past. With introduction of the decaying factor(), the extended integration feedback is given by

$$\int_0^t e^{\lambda(t-\tau)} \Delta f(\tau) d\tau \tag{2}$$

with its s-domain function of $1/(s+\lambda)$

In the extended integral control concept, it is obvious that the past error can be ignored in the integral of error forward to the plant after enough time has passed.

The extended integral control has another advantage to control frequency in LFC system of power systems. It is well known that the conventional PI controller makes the frequency droop to be zero. That is, the PI controller produces a control signal which makes the frequency deviation to be zero as follows:

$$\delta^i = \int_0^t \Delta f_i dt + \delta_{oi} \tag{3}$$

It is noted that the initial time for integration of the frequency deviation error is difficult tobe set same for all generators. In other words, the determination of δ_{oi} in eq.(3) is difficult to be same. This is the reason that all generators are not controlled by the PI controller. In practice, one of all generators is controlled by the PI controller and the others are controlled by the proportional controller.

However, the extended integral controller does not need the same initial time, so that it can be applied to any generator simultaneously. Consequently, the extended integral control scheme can produce better control performance than the proportional control scheme.

As shown in eq.(2), the performance of the extended integral control is greatly dependent on the decaying factor. The extended integral controller applied to LFC introduces a degree of deviation as an index to the system dynamics. The degree of deviation can be given as a function of frequency deviation, and its rate. In eq.(4), the weighting factors should be determined by the system characteristics.

$$\textit{Degree of Deviation } d = \sqrt{k_1 \Delta\omega^2 + k_2 \dot{\omega}^2} \tag{4}$$

In addition, the system performance can be evaluated with the following performance index.

$$\Pi = \int_{t_0}^{\infty} (a_1 \Delta\omega^2 + a_2 \Delta\delta^2) dt \tag{5}$$

where 1, 2 : weighting factors

On the basis of deviation degree (4) and performance index (5), the decaying factor and the feedback gains should be determined to achieve the optimality of system performance. The decaying factor should be changed according to the degrees of deviation in several levels. For instance, the large decaying factor should be selected to reduce rapidly the effects of the error for large overshoot, while the small decaying factor for small overshoot.

Problem of Extended Integral Control

Because of the inherent characteristics of the changing loads and the system non-linearities such as GRC, there is no effective analytical method to determine optimal parameters quickly for real time application. Especially, because of its time-varying characteristic, the optimal decaying factor is difficult to be selected analytically.

In order to solve the problems of parameter tuning for the extended integral control, this study searches for AI-based technique to identify the optimal parameters. Artificial Neural Networks(ANNs) and Fuzzy systems can be successfully applied to LFC problem with promising results. The main feature of these techniques is that they provide a model-free description of control systems and do not require model identification[5].

3. Fuzzy Logic Based Extended Integral Control Scheme

This study presents an application of fuzzy logic based method to determine the optimal parameters for the extended integral control scheme. Under the environment that the system changes over a wide range of operating condition, the extended integral control scheme can provide satisfactory control performance if its parameter is well-tuned. It is an important point that the time-varing decaying factor in the extended integral control should be changed in accordance with the degree of frequency deviation. Becauseof its time-varing characteristic, the optimal decaying factor is difficult to be selected analytically. Fuzzy is normally used when the relationships between the system dynamics and operation conditions are known.

By adopting fuzzy set theory, the decaying factor can be determined quickly to respond to the variation of the feedback signals. The fuzzy logic based extended integral control scheme is shown in Fig. 2.

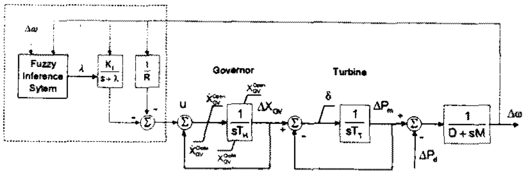


Fig. 2 Fuzzy logic based Extended Integral Control Scheme

The proposed controller consists of an extended integral controller and a fuzzy logic based parameter tuner which adjusts the decaying factor λ according to decision rules. This study builds a fuzzy rule base with use of the change of frequency and its rate as inputs. Table 1 shows the decision rules.

Table 1 Decision Rules

		Frequency Deviation $\Delta\omega$				
		LN	MN	ZO	MP	LP
$\Delta\dot{\omega}$	LN	VP	LP	SP	LP	VP
	ZO	VP	LP	ZO	LP	VP
	LP	VP	LP	SP	LP	VP

For example, the rules are interpreted as follows:

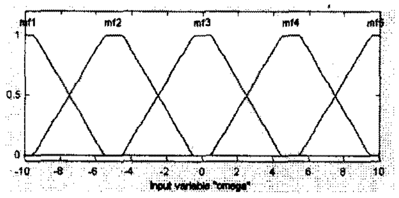
If frequency deviation $\Delta\omega$ is LN and its derivative $\Delta\dot{\omega}$ is LN, then the decaying factor λ is VP

The input signalsare divided into five linguistic variables using fuzzy set notations such as large negative(LN), medium negative(MN), zero(ZO), medium positive(MP), and large positive(LP). The output signal is also divided into five levels such as zero(ZO), small positive(SP), medium positive(MP), large positive(LP), and very large positive(VP). A set of decision rules expressed in linguistic variables is established to relate input signals to the decaying factor. Here, it should be noted that more emphasis is placed on the frequency deviation $\Delta\omega$ than its rate $\Delta\dot{\omega}$.

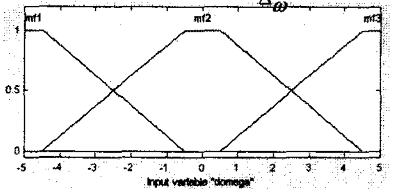
As can be observed from Table 1, the decision rules determine the decaying factor in such a way that the large decaying factor is selected to reduce rapidly the effectsof the error for large overshoot, while the small one for small overshoot. With the optimal time-varing decaying factors in real time, the fuzzy logic based extended integral control scheme provides satisfactory performance even with presence of GRC. The process of determining the decaying factor by fuzzy logic method is more reasonable and easier than the process by the heuristic method in earlier work[4]. The previous work required too many trials of simulation to get the optimal decaying factor, which makes the proposed controller impractical. However, the fuzzy logic based method provides a reasonable and convenient way to select the optimal decaying factor and enables the proposed controller to be practical.

Membership Function

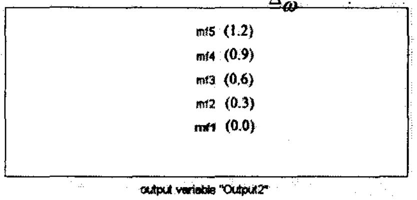
The membership functions are selected by experience. The input variable $\Delta\omega$ is divided into five fuzzy sets, mf1(LN), mf2(MN), mf3(ZO), mf4(MP), and mp5(LP). The input variable $\Delta\dot{\omega}$ is divided into three fuzzy sets, mf1(LN), mf2(ZO), and mf3(LP). The output variable is divided into five constant fuzzy sets, such as mf1(ZO), mf2(SP), mf3(MP), mf4(LP), and mp5(VP). Fig. 3 shows the membership functions



(a) Input Variable $\Delta\omega$



(b) Input Variable $\Delta\dot{\omega}$



(c) Output Variable λ : constants

Fig. 3 Membership functions

Fuzzy rules set

Some meaningful decision rules in Table 1 are used in simulation. That is, decision rules are as follows:

1. If ($\Delta\omega$ is mf1), then output λ is mf5
2. If ($\Delta\omega$ is mf5), then output λ is mf5
3. If ($\Delta\omega$ is mf2), then output λ is mf4
4. If ($\Delta\omega$ is mf4), then output λ is mf4
5. If ($\Delta\omega$ is mf3) and ($\Delta\dot{\omega}$ is mf2), then output λ is mf1
6. If ($\Delta\omega$ is mf3) and ($\Delta\dot{\omega}$ is mf1), then output λ is mf2
7. If ($\Delta\omega$ is mf3) and ($\Delta\dot{\omega}$ is mf3), then output λ is mf2

4. Simulation Results

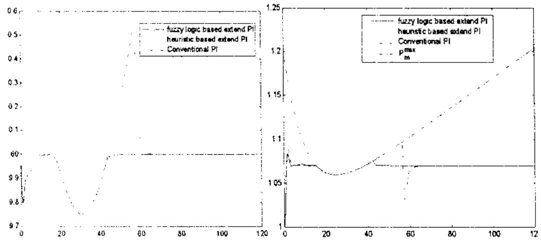
The fuzzy logic based extended integral control for LFC has been tested for the single machine system with a unit step disturbance. The simulation has been conducted with Fuzzy Logic Toolbox and Simulink in MATLAB 5.3 whose fuzzy inference system is Sugeno type. The membership function and fuzzy rule set is developed by some general experience in a heuristic way.

The tested system is shown in Fig. 2 with the presence of GRC and rate limit on valve position. To prevent the excessive movement, a limiter is also added to the valve position. Typical parameters for steam turbine are as follows:

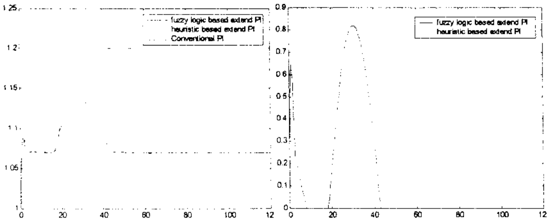
Table 2. Steam-Turbine Parameter

Parameter	Value	Parameter	Value
GRC	0.1pu/min	H	6.0
TH	0.1	Dpu	2.0
TT	0.3	f0	60
TB	10.0	R	0.05
X_{GV}^{Open}	1.2pu	X_{GV}^{Close}	0.4pu
$\dot{X}_{GV}^{Open}$	0.4pu/s	$\dot{X}_{GV}^{Close}$	-1.5pu/s

The *f*, Pm, XGV, Pmaxresponses of the proposed controller under GRC are shown in Fig. 5, compared with those of the heuristic method based extended integral controller[4] and conventional controller under GRC.



(a) Frequency (b) Mechanical Power



(c) Valve Position (d) Decaying factor

Fig. 5 Dynamic responses for a unit step disturbance

As shown in Fig. 5(a), the frequency response with the fuzzy logic based extended integral controller under GRC has much less overshoot than the conventional controller under GRC for first ten seconds and then a little overshoot. As pointed in the previous work[4], this results from the fact that the extended integral control is using a decaying factor to reduce the effects of the error in the past. However, compared with the heuristic method based extended integral controller, the fuzzy logic based controller provides a little better performance. It can be explained from Fig. 5(d) that the decaying factor by fuzzy logic method changes continuously to response the deviation of frequency, whereas the one by the heuristic method changes in the form of piecewise constant according to the deviation of frequency.

5. Conclusion

This study presented an application of fuzzy logic based method to determine the optimal parameters for the extended integral control scheme. Since the conventional PI controller with fixed gains has been designed at nominal operating conditions, it failed to provide best control performance over a wide range of operating conditions. In order to overcome this drawback, Moon et al.[4] have suggested a new LFC scheme adopting an extended PI control. The performance of the extended integral control isgreatly dependent on the decaying factor. However, becauseof its time-varing characteristic, the optimal decaying factor is difficult to be selected analytically. By adopting fuzzy set theory, the decaying factor can be determined quickly to respond to the variation of the feedback signals. This study builds a fuzzy rule base with use of the change of frequency and its rate as inputs. The computer simulation has been conducted for the single machine system. The simulation results showed that the proposed fuzzy logic based controller yields more improved control performance than the conventional PI controller. Although the results by fuzzy logic method are similar with those by the heuristic method, they have been easily obtained. It is concluded that the fuzzy logic based extended integral control scheme provides good performance even in the presence of GRC for any size of load change.

Further research should be done to optimize the membership functions which are to be selected on the basis of experience.

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