HVDC 시스템을 위한 진화론적으로 최적화된 자기 동조 퍼지제어기

Genetically optimized self-tuning Fuzzy-PI controller for HVDC system

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Abstract - In this paper, we study an approach to design a self-tuning Fuzzy-PI controller in HVDC(High Voltage Direct Current) system. In the rectifier of conversional HVDC system, turning on, turning off, triggering and protections of thyristors have lots of problems that can make the dynamic instability and cannot damp the dynamic disturbance efficiently. The above problems are solved by adapting Fuzzy-PI controller for the fire angle control of rectifier.[7] The performance of the Fuzzy-PI controller is sensitive to the variety of scaling factors. The design procedure dwells on the use of evolutionary computing(Genetic Algorithms, GAs). Then we can obtain the optimal scaling factors of the Fuzzy-PI controller by Genetic Algorithms. In order to improve Fuzzy-PI controller, we adopt FIS to tune the scaling factors of the Fuzzy-PI controller on line. A comparative study has been performed between Fuzzy-PI and self-tuning Fuzzy-PI controller, to prove the superiority of the proposed scheme.

Key Words :Fuzzy-PI controller, Self-tuning controller, HVDC, Genetic Algorithms(GAs)

1. Introduction

From the beginning of electric power history, DC transmission lines and cables have less expensive and more advantageous than those for three-phase AC transmission. As power generation and demand are increasing, in order to handle large bulk of power, we need utilize the savings that DC transmission offers. Not only it is used for long distance power transmission, also it is being used as a part of the AC network to enhance the stability of the system.

But the operation and control of HVDC links pose a challenge for the designers to choose the proper control strategy under various operation conditions[1]. The HVDC system traditionally uses PI controllers to control the DC current thereby keeping the current order at the required level. However, in controlling a nonlinear plant such as the fire angle of the rectifier side, the model controls such as fuzzy controllers show better performance to the dynamic disturbances than traditional PI controllers.

Generally speaking, fuzzy controllers show good control performances when systems are complex and cannot be analyzed using traditional methods. But we cannot obtain good control performances if fuzzy membership functions are inaccurate. When designing fuzzy controllers, it's difficulty to determine shapes of membership functions that are usually obtained by a large of try-and-error or experiences of the human being experts.

To circumvent the above problem, we study an approach to design a Fuzzy controller based on GAs in HVDC system. The paper also includes the experimental study dealing with the rectifier side current controller and deriving the optimal control parameters through GAs. The performance of systems under control is evaluated by the method of IAE(Integral of the Absolute value of Error)[2].

A Node Circuit Analysis simulation program was used in this study. The program has the capability of detailed modeling of transmission lines.[3]

2. HVDC System Model

2.1 HVDC Model

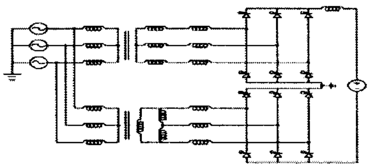

Fig. 1 HVDC real model circuit

A two poles point-to-point HVDC system has been simulated under the environment of MATLAB[3]. Each element on either side of the DC link and the transmission lines is represented in detail.

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Generally, HVDC system can be divided into four parts - generator side, rectifier side, inverter side and the load bus. In this paper, we only discuss about rectifier side. The system shown in Fig.1 is re-divided into four parts - generator, transformer including one Y-Y connection type and one Y-Δconnection type, the 12-pulse rectifier consisting of two 6-pulse bridges in series and voltage resource containing inverter side and the load bus.

2.2 Rectifier Control System

Fig.2(a) shows the characteristic curve of current control. It is operated through the constant current control(AD) of a rectifier and a constant extinction angle control(BC) of an inverter in steady state.

The constant current control(AD) is the control that keeps the current of DC line uniform. The firing angle is adjusted with current error, to maintain the DC current constant. As shown in Fig.2(b), therefore, we use the firing angle as the output of rectifier current controller, whose inputs are current error and its derivative.

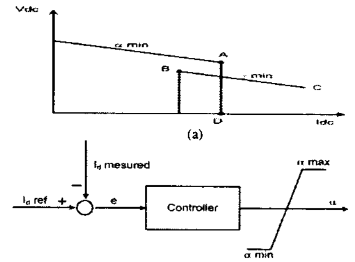

Fig. 2 (a)HVDC control characteristic (b)Block diagram of the rectifier controller

3. Proposed Methods of Controller Design

3.1 Self-tuning Fuzzy-PI Controller

The designed strategies of Fuzzy-PI controller based on GAs has been applied[7]. To improve the dynamic performance for rectifier current controller in HVDC system, A strategy of self-tuning Fuzzy-PI controller is proposed, as shown in Fig.4.

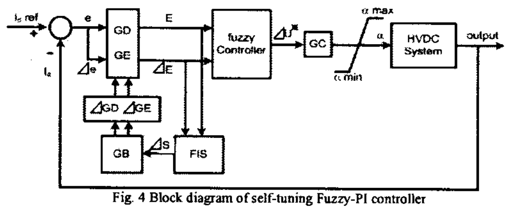

Fig. 4 Block diagram of self-tuning Fuzzy-PI controller

Here, we add a self-tuning side on Fuzzy-PI controller. We adapt FIS to tune GD and GE on-line.

In the AC side of rectifier, the current error(e) and its derivative error(Δe) are sensitive. It's difficult to determine their ranges. The ranges of the input variables(E, ΔE) of the designed controller[7] are always[-1,+1] and [-1,+1] respectively no matter what the ranges of the current error(e) and its derivative error(Δe) are. We can adjust the scaling factors by means of the input variables(E, ΔE). The output(Δs) interval of FIS has been determined. A new scaling factor(GB) is added to balance the output variables(ΔGD, ΔGE).

$$e(k) = I_{dref}(k) - I_d(k) \quad (1)$$

$$\Delta e(k) = \frac{e(k) - e(k-1)}{T} \quad (2)$$

$$E(k) = e(k) \times GD \quad (3)$$

$$\Delta E(k) = \Delta e(k) \times GE \quad (4)$$

$$w_i = \min[\mu_A(E), \mu_B] \quad (5)$$

$$\Delta u^* = \frac{\sum_{i=1}^{n} w_i D_i}{\sum_{i=1}^{n} w_i} \quad (6)$$

$$\alpha(k) = \Delta u^*(k) \times GC \quad (7)$$

$$\alpha(k) = \alpha(k-1) - \Delta\alpha(k) \quad (8)$$

From Fig. 3 and equations (1)~(6), we can get,

$$GD(new) = GD(old) - \Delta GD \quad (10)$$

$$GE(new) = GE(old) - \Delta GE \quad (11)$$

$$\Delta GD = \Delta s * GB * 0.001 \quad (12)$$

$$\Delta GE = \Delta s * GB * 0.00001 \quad (13)$$

Here, the scaling factors(GD,GE) are derived by GAs in Part 2. GB is coefficient that adjusts the ΔGD and ΔGE, when ΔS>=0, GB is 24.5; when ΔS<0 GB is 1/24.5. Then, we should make a FIS.

The above FIS consists of rules of the form[4].

IF E is Al and ΔE is Bl, THEN ΔU* is Cl

Where Al, Bl and is Cl are fuzzy sets, and l=1,2,···,m.

Suppose that the domains of interval of the two input variables(E, ΔE) and the output variable(ΔS) are [-1,+1] and [-1,+1] respectively. The inputs E and ΔE are fuzzified into 5 sets, as show in Fig. 5,

NB: Negative Big, NM: Negative Mid, ZO: Zero, PM: Positive Mid and PB: Positive Big.

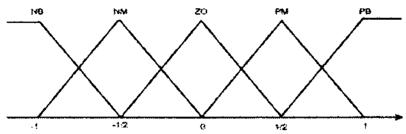

Fig. 5 Membership functions for E and ΔE

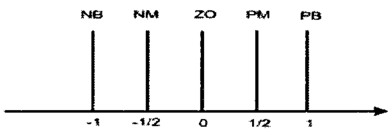

Fig. 6 Membership functions for ΔS

Thus, a complete fuzzy rule consists of 25 rules. For simplicity, assume that Cl is the fuzzy sets NB(-m2), NM(-ml), ZO(0), PM(ml) and PB(m2), whose membership functions are shown in Fig.6.

TABLE 1 The Collection of the Rules

E\ΔE	PB	PM	ZO	NM	NB
PB	-m2	-m2	-ml	0	-ml
PM	-m2	-ml	0	-ml	0
ZO	-ml	0	-ml	0	ml
NM	0	-ml	0	m2	m2

NB	-m1	0	m1	m2	m2

The collection of the rules is shown in Table I .The min-max product by equation(5) is used for the compositional rule of inference and the defuzzification method is the center of gravity as expressed by equation(6).

3.2 Genetic Algorithms(GAs)

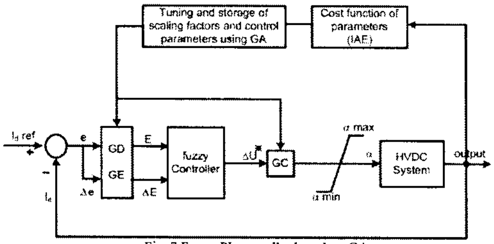

Fig. 7 Fuzzy-PI controller based on GAs

In this study, we use GAs to find the scaling factors of Fuzzy-PI controller[7], as shown in Fig.7[5]. To use a GA, we need represent a solution to our problem as a genome. To find the best one, the GAs create a population of solutions and apply genetic operators such as mutation and crossover to evolve the solutions[6]. To obtain the satisfactory dynamic performance of transient process, we adapt IAE to be the smallest objective function. Select the equation(9) to be the optimal fitness of the parameter determination[2].

$$J = \int_0^t |e(\tau)| d\tau \quad (9)$$

4 Simulation and Studies

The parameters of self-tuning Fuzzy-PI controller are as follows:

GB: 24.5, GC: 0.04, GD: 0.00005, GE: 0.008

In this part, the self-tuning Fuzzy-PI controller is compared with Fuzzy-PI controller in the same case, as shown in Fig.8.

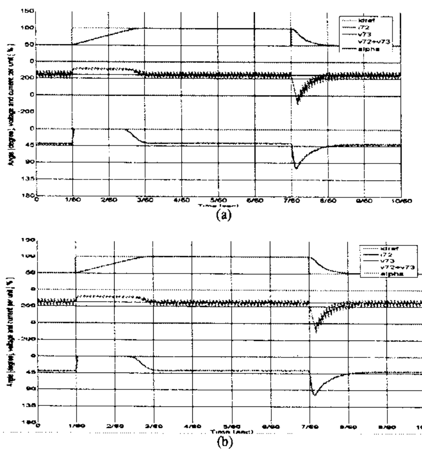

Fig. 8 (a) Self-tuning Fuzzy-PI controller (b) Fuzzy-PI controller

After comparison of Self-tuning Fuzzy-PI controller with Fuzzy-PI controller, we know that the Self-tuning Fuzzy-PI controller has better performance in terms of overshoot and undershoot, as shown in Table II. Not only the overshoot and undershoot are decreased in Self-tuning Fuzzy-PI controller, and also the performance index and rising time in self-tuning Fuzzy-PI controller are smaller.

TABLE II

Compare Self-tuning Fuzzy-PI with Fuzzy-PI

	Self tuning Fuzzy PI	Fuzzy PI
$J = \int_0^t \lvert e(\tau)\rvert d\tau$	1.1035	1.1332
rising time	1051 × Δt	1401 × Δt
overshoot	0.6029%	0.7862%
undershoot	0.5%	1.2990%
*note: Δt = 0.25[sec]/15000[sample]		

5 Conclusions

In this paper, we study the self-tuning Fuzzy-PI controller and GAs. We use GAs to find the optimal parameters of Fuzzy-PI controller. Then, the self-tuning Fuzzy-PI controller was compared with Fuzzy-PI controller by the simulation study. Through the comparison of two types controller in the same case, the self-tuning Fuzzy-PI controller shows the better performances in terms of overshoot, undershoot and rising time. Also its performance index is better. Therefore, the proposed design strategy of self-tuning Fuzzy-PI controller can be useful tools for system stability and fast damping the system disturbance in HVDC system.

Finally, in the future study, we would like to focus on the Rough set theory and apply it in HVDC system.

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