

HVDC 시스템에 대한 유전자 알고리즘을 사용한 새로운 퍼지 제어기의 설계

A New Design of Fuzzy controller for HVDC system with the aid of GAs

왕 중 선, 양 정 제, 노 석 범, 안 태 천*

(Zhong-xian Wang, Jueng-je Yang, Seok-beom Rho, and Tae-chon Ahn)

Abstract : In this paper, we study an approach to design a Fuzzy PI controller in HVDC(High Voltage Direct Current) system. In the rectifier of traditional 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. In order to solve the above problems, we adapt Fuzzy PI controller for the fire angle control of rectifier. 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 factors of the Fuzzy PI controller by Genetic Algorithms. A comparative study has been performed between Fuzzy PI controller and traditional PI controller, to prove the superiority of the proposed scheme.

Keywords : fuzzy PI and PI controllers, HVDC system, Genetic Algorithms(GAs), simulation

I. 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, but also it is being used as a part of the AC network to enhance the stability of the system[1].

But the operation and control of HVDC links pose a challenge for the designers to choose the proper control strategy under various operation conditions[2]. 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[3].

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, in this paper, we study a new approach to design a fuzzy controller using Genetic Algorithms(GAs) in HVDC system. The paper also includes the experimental study dealing with the rectifier side current controller and deriving the optimal control parameters based on GAs. The performance of systems under control is evaluated by the method of IAE(Integral of the Absolute value of Error)[4].

A Node Circuit Analysis simulation program was used in this study. The program has the capability of detailed modeling of transmission lines. In addition, the program is very similar with the real HVDC system[5].

II. HVDC System Model

A two pole point-to-point HVDC system has been simulated under the environment of MATLAB[5]. Each element on either side of the DC link and the transmission lines is represented in detail.

Part 1: HVDC model system

Generally speaking, the 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. It's not necessary to illustrate each part in detail in our model. So, we assume the inverter side and the load to be voltage resource. The system shown in Fig. 1

* 책임저자(Corresponding Author)

논문접수 : 2005. 11. 15., 채택확정 : 2006. 2. 5.

왕중선, 양정제, 노석범 : 원광대학교 제어계측공학과

(zhxwang@wonkwang.ac.kr/yjksm@wonkwang.ac.kr/nado@wonkwang.ac.kr)

안태천 : 원광대학교 전기전자및정보공학부(tcahn@wonkwang.ac.kr)

※ This work has been supported by KESRI (R-2004-B-133), which is funded by MOCIE(Ministry of commerce, Industry and Energy).

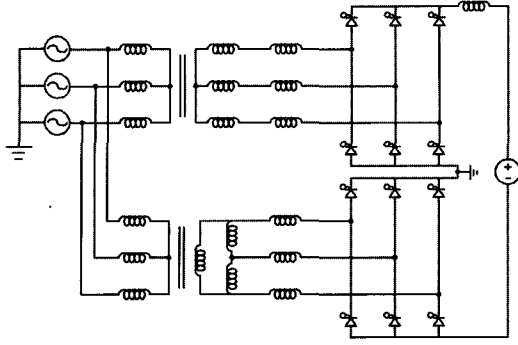


Fig. 1. HVDC real model circuit.

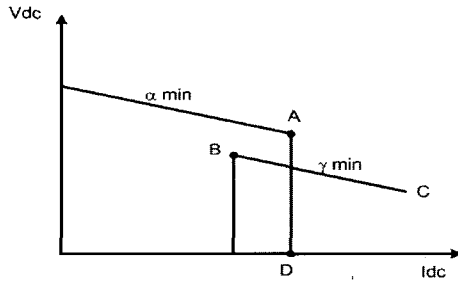


Fig. 2. HVDC control characteristic.

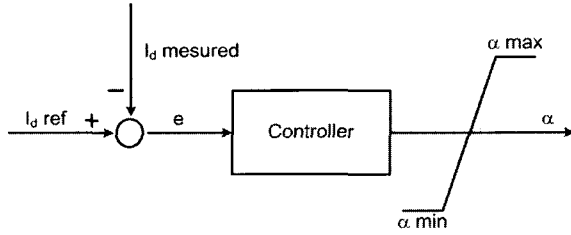


Fig. 3. Block diagram of the rectifier controller.

is re-divided into four segments - generator, transformer including one Y-Y connection type and one Y-Δ connection type, the 12-pulse rectifier consisting of two 6-pulse bridges in series and voltage resource containing inverter side and the load bus[6].

Part 2: Rectifier control system

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

The constant voltage 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. 3, therefore, we use the firing angle as the output of rectifier current controller, whose inputs are current error and its derivative.

III. Proposed Methods of Controller Design

Design method of fuzzy controller of controller based on Genetic Algorithms(GAs) to improve the dynamic performance for rectifier current controller in the HVDC system

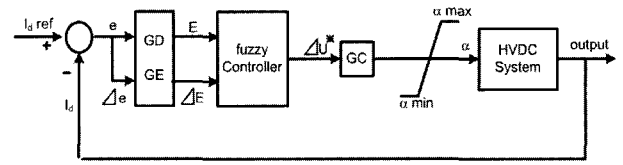


Fig. 4. Block diagram of fuzzy PI controller.

is as follows:

Part 1: The Fuzzy PI controller

The block diagram of Fuzzy PI controller is shown in Fig. 4[8].

Here, the current error(e) and its derivative error(Δe) are used to adjust the input variables(E, ΔE) by the scaling factors(GD,GE) that we can derive from the Genetic Algorithms(GAs).

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

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

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

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

$$w_i = \min[\mu_{A^i}(E), \mu_{B^i}(\Delta E)] \quad (5)$$

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

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

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

From equation (1)~(8) and Fig. 4, we know if we want to control the fire angle, we have to determine the parameters(GC,GD,GE). So, we adapted the GAs to find the optimal parameters. We will discuss about the GAs and its estimation in detail in Part 2. Now, we need make a FIS(fuzzy inference system).

The above Fuzzy PI controller consists of rules of the form[7].

IF E is A^l and ΔE is B^l , THEN ΔU^* is C^l Where A^l , B^l and C^l are fuzzy sets, and $l=1,2,\dots,m$.

Suppose that the domains of interval of the two input variables(E, ΔE) and the output variable(ΔU) are [-1,+1] and [-1,+1] respectively. The inputs E and ΔE are fuzzified into 7 sets, ie.,

NB: Negative Big, NM: Negative Medium, NS: Negative small, ZO: Zero, Ps: Positive small, PM: Positive Medium and PB: Positive Big.

The membership functions are as shown in Fig. 5. Thus, a complete fuzzy rule base consists of 49rules. For simplicity, assume that C^l is the fuzzy sets NB(m3), NM(m2), NS(m1), ZO(0), PS(-m1), PM(-m2) and PB(-m3),whose membership functions are shown in Fig. 6.

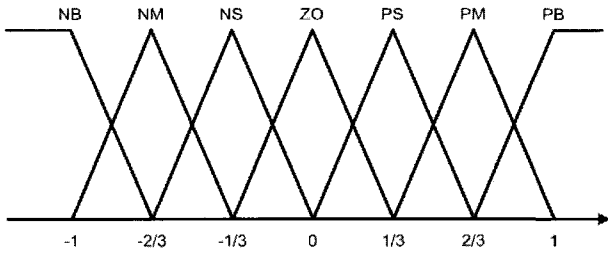
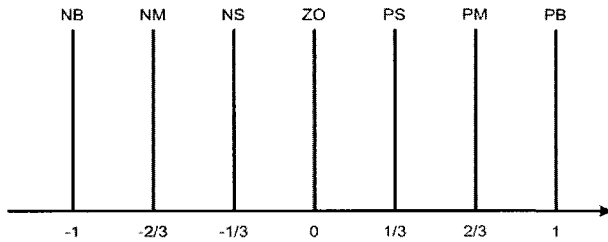
Fig. 5 Membership functions for E and ΔE .Fig. 6. Membership functions for ΔU^* .

Table 1. Fuzzy control rules.

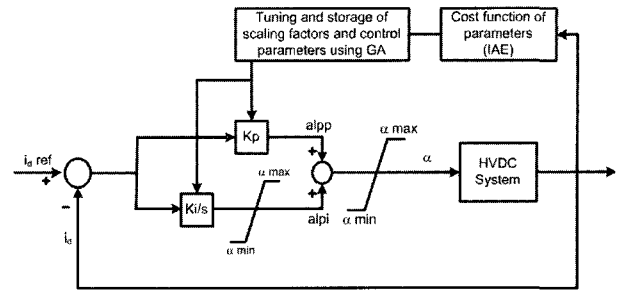
		ΔE						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	-m3	-m3	-m3	-m3	-m2	-m1	0
	NM	-m3	-m3	-m3	-m2	-m1	0	m1
	NS	-m3	-m3	-m2	-m1	0	m1	m2
	ZO	-m3	-m2	-m1	0	m1	m2	m3
	PS	-m2	-m1	0	m1	m2	m3	m3
	PM	-m1	0	m1	m2	m3	m3	m3
	PB	0	m1	m2	m3	m3	m3	m3

The collection of the rules is shown in Table 1. 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).

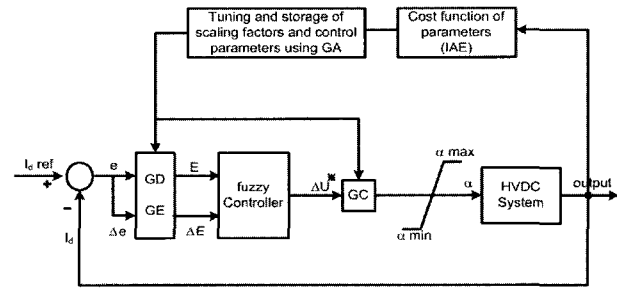
Part 2: Genetic algorithms(GAs)

Genetic algorithms(GAs) were formally introduced in the United States in 1962 by Professor Holland at University of Michigan, which become one parallel stochastic search optimization method through simulation nature genetic mechanism and the biological theory of evolution. The continuing price/performance improvements of computational systems has made them attractive for some types of optimization. In particular, genetic algorithms work very well on mixed (continuous and discrete), combinatorial problems. They are less susceptible to getting 'stuck' at local optima than gradient search methods. But they tend to be computationally expensive.

In this paper, we use GAs to find the parameters of the scaling factors, shown in Fig. 7[8]. To use a genetic algorithm, we need represent a solution to our problem as a genome (or chromosome). In order to find the best one(s), the genetic algorithms create a population of solutions



(a) Traditional PI controller



(b) Fuzzy PI controller based on GAs

Fig. 7. (a) Traditional PI controller (b) Fuzzy PI controller based on GAs.

Table 2. The coefficients of GAs simulation.

Items	PI controller	Fuzzy controller
No. of initial population	30	30
Probability of crossover	0.9	0.9
Probability of mutation	0.033	0.033
No. of generations	100	100

and apply genetic operators such as mutation and crossover to evolve the solutions[9]. In order 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 most optimal fitness of the parameter determination[4].

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

The simulation coefficients and architectures of populations are described in Table 2.

4. Simulation and Studies

In last chapter, we used GAs to find the optimal parameters. Then, we get the final optimal parameters for Fuzzy PI(GC, GD, GE) and PI(Kp, Ki) controllers using the same procedure.

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

Kp: -0.1492, Ki: -16.00

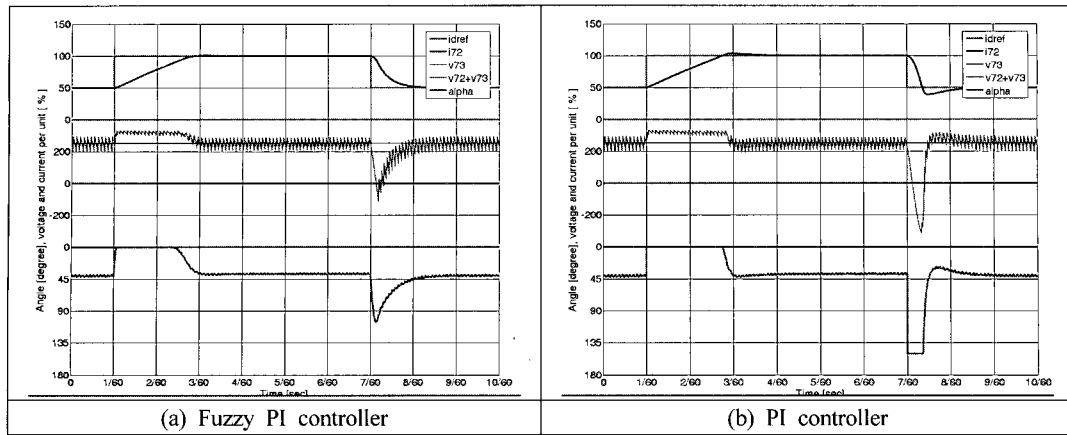


Fig. 8. The performance comparison of fuzzy PI and PI controllers in case of balance states.

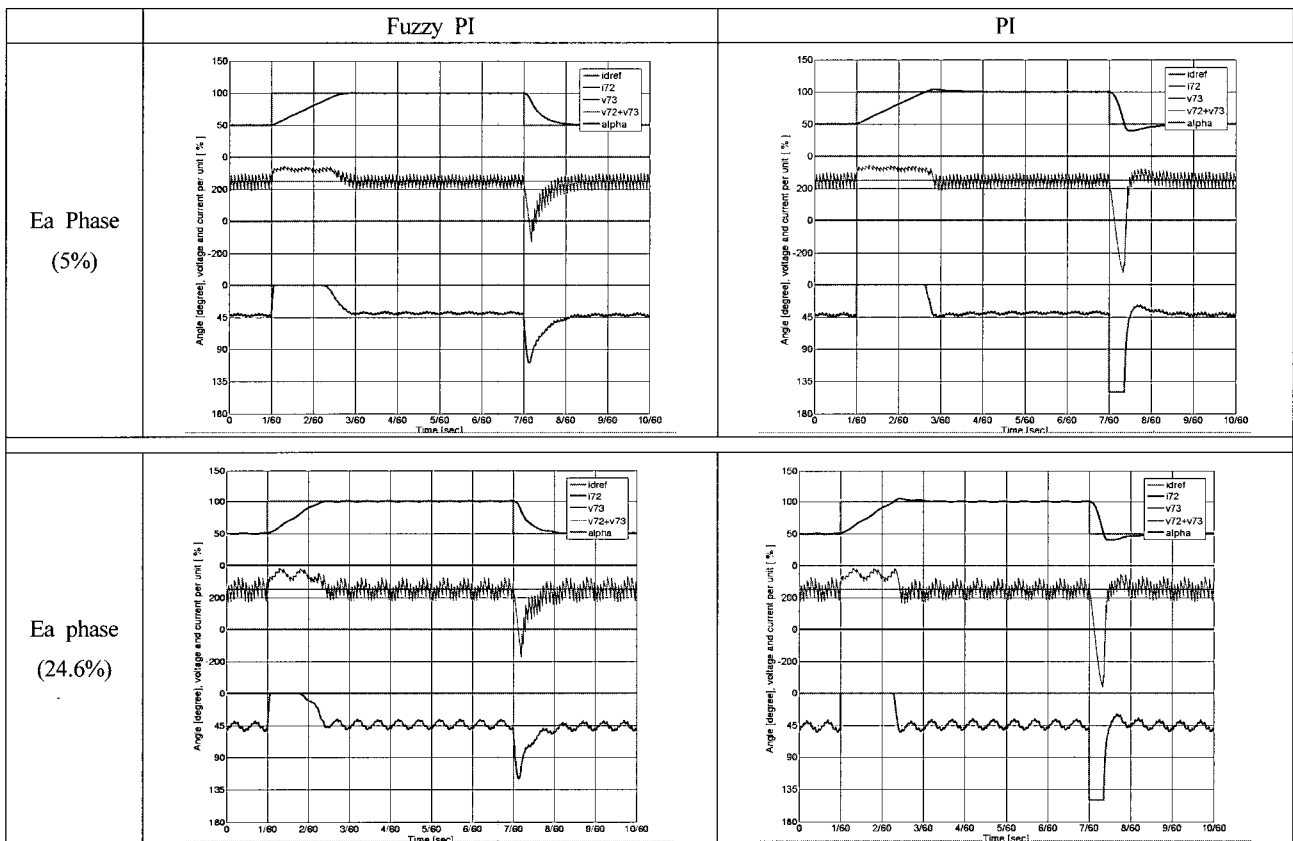


Fig. 9. The performance comparison of fuzzy PI and PI controllers in case of difference Ea phase.

Table. 3. Compare fuzzy PI with PI.

	Fuzzy PI	PI
$J = \int_0^t e(\tau) d\tau$	J=1.1038	J=1.1323
rising time	1401×Δt	1403×Δt
overshoot	0.5545%	3.7330%
undershoot	1.3016%	21.661%

*note: Δt = 0.25[sec]/15000[sample]

In this part, we compare Fuzzy PI with PI controllers in

case of balance and unbalance states.

Case 1 : Balance states

Using the above fixed gains, we get results in case of balance states, as shown Fig. 8.

After comparison of Fuzzy PI and PI controllers, we know the Fuzzy PI has better performance in terms of overshoot and undershoot, as shown table 3. Not only there are little overshoot and undershoot in fuzzy controller, and also IAE in fuzzy controller is smaller. If not consider rising time sincerely, the rising time is same among two

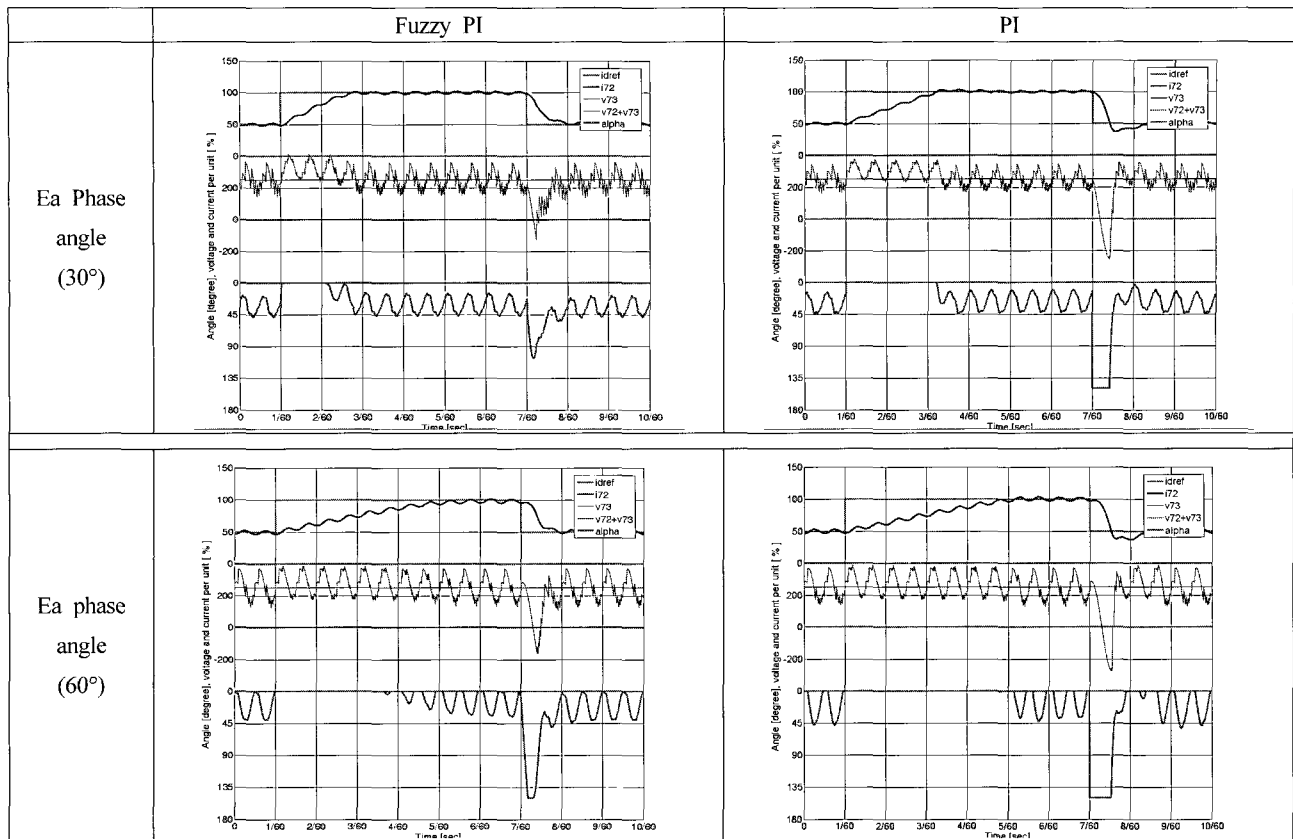


Fig. 10. The performance comparison of fuzzy PI and PI controllers in case of difference Ea phase angle.

types controller. When the reference direct current changed, the voltage and alpha vary small.

Case 2 : unbalance states.

We change Ea phase and Ea phase angle, respectively. We can get result under the different situations, as shown in Fig. 9 and Fig. 10.

We simulate the problems of the real system such as unbalance AC voltage phase and phase angle under the different case. The performances comparison of Fuzzy PI controller and PI controller in case of different Ea phase and Ea phase angle are shown in Fig. 9 and Fig. 10, respectively. When Ea phase and Ea phase angle varied in ranges $(0, 0.247 \times E_a)$ and $(0, 60/180 \times \pi)$, respectively, the fuzzy controller shows better performance in term of overshoot and undershoot. From the results, we can know the fire angle(α) is in range $[0, 111.48]$ in fuzzy controller and the maximum angle is also smaller.

5. Conclusions

In the paper, we study the Fuzzy PI controller and Genetic Algorithms(GAs). We use GAs to find the optimal parameters. Then, we compare the fuzzy controller with traditional PI controller. Through the comparison of two types of controller in different case, we know the Fuzzy PI controller shows the better performances in terms of

overshoot and undershoot. And, the stabilizing time for two types controller is the same. Therefore, the proposed design method of Fuzzy PI controller can be useful tools for system stability and fast damping the system disturbance in HVDC system.

Finally, we would like to apply accident data of real HVDC system to our simulator and we will improve fuzzy PI controller based on GAs.

Reference

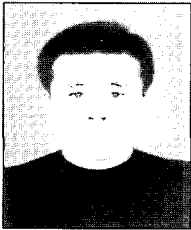
- [1] F. Nozari, H. S. Patel, "Power electronics in electric utilities: HVDC power transmission systems," *Proceedings of the IEEE*, vol. 76, no. 4 April 1988.
- [2] A. Routray, P. K. Dash, and S. K. Panda, "A fuzzy self-tuning PI controller for HVDC links," *IEEE Transactions on Power Electronics*, vol. 11, no. 5, Sep, 1996.
- [3] J. Y. Yoon, G.-H. Hwang and J. H. Park, "A genetic algorithm approach to design the optimal fuzzy controller for rectifier current control in HVDC system" *Journal of Electrical Engineering and Information Science*, vol. 3, no. 6, Page 792~797, Dec, 1998.
- [4] 劉金琨, 先進 PID 控制及其 MATLAB 仿真, 電子工業出版社, October, 2002.
- [5] T.-C. Ahn and so on, "Development of adaptive granular

control technique for HVDC transmission system" report, Feb, 2005.

- [6] P. K. Dash, A. C. Liew and A. Routray, "HIGH-performance controllers for HVDC transmission links" *IEE Pro-Gener.Transm.Distrib.*, vol. 141, no. 5, Sep, 1994.
- [7] L.-X. Wang, *A Course of Fuzzy System and Control* Prentice Hall, 1997.
- [8] S.-K. Oh, W. Pedrycz, S.-B. Rho and T.-C. Ahn,

"Parameter estimation of fuzzy controller and Its application to inverted pendulum" *Engineering Applications of Artificial Intelligence*, vol. 17, Issue 1, February 2004, Pages 37-60.

- [9] 周孝信, 交直流電力系統の分析和控制, 2004.
- [10] P. K. Dash, A. Routray, S. K. Panda and A. C. Liew, "Fuzzy tuning of da ling controllers" *IEEE Catalogue*, no. 95TH8130.



왕 중 선

2004년 하얼빈이공대학교 전기공학과 졸업. 2004년 흑룡강 대학교 행정관리과 졸업. 현재 원광대학교 대학원 석사 재학중. 관심분야는 인텔리전트 전력 제어 시스템.



양 정 제

2005년 원광대 전기전자 공학부 졸업. 현재 동 대학원 석사 재학중. 관심분야는 인텔리전트 전력 제어 시스템.



노 석 범

1994년 원광대 제어계측공학과 졸업. 1996년 동 대학원 컴퓨터 공학과 석사. 현재 동 대학원 박사 수료. 관심분야는 인텔리전트 제어 시스템.



안 태 천

1980년 연세대학교 전기공학과 공학석사. 1986년 연세대학교 전기공학과 공학박사. 1981년~현재 원광대학교 전기전자 및 정보공학부 교수. 관심분야는 지능형 계측 제어시스템, 지능형 패턴 인식, 디지털 제어 시스템.