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Damping of Low frequency Oscillations Using GA based Unified Power Flow Controller

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Abstract— The paper presents a new control method of damping low frequency power system oscillations using Genetic Algorithm (GA) based Unified Power Flow Controller (UPFC) Phillips-Herffron model of a single-machine power system equipped with a UPFC is used to model the system. UPFC controller based upon phase angle of shunt converter (exciter) δ_E has been designed. The effectiveness of UPFC controller without using GA and GA based UPFC controller (GA-UPFC) has been demonstrated at variable loading conditions.. Respective models have been developed and simulated in Matlab/Simulink. The results of these studies show that the designed controller has an excellent capability in damping power system oscillations.

Keywords: UPFC; Genetic Algorithm; Damping controller; Low frequency oscillations.

NOTATIONS

Cdc	:	dc link capacitance
D	:	damping constant
H	:	inertia constant (M = 2H)
Ka	:	AVR gain
Kdc	:	gain of damping controller
Gc	:	Phase compensater transfer function
mE	:	modulation index of shunt converter
Pe	:	electrical power of the generator
Pm	:	mechanical power input to the generator
*T*1,T2	:	time constants of phase compensator
Ta	:	time constant of AVR
Tdo	:	d-axis open circuit time-constant of generator
Vb	:	infinite bus voltage
Vdc	:	voltage at dc link
Vt	:	terminal voltage of the generator
XB	:	reactance of boosting transformer (BT)
XBv	:	reactance of transmission line
Xd	:	direct axis steady-state synchronous reactance of generator
XE	:	reactance of excitation transformer (ET)
Xe	:	equivalent reactance of the system
Xq	:	quadrature axis steady-state synchronous reactance of generator
XtE	:	reactance of transformer
X'd	:	direct axis transient synchronous reactance of generator
δB	:	phase angle of series converter voltage
δE	:	phase angle of shunt converter voltage
ω*n*	:	natural frequency of oscillation (rad/sec)

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I. INTRODUCTION

Nowadays, FACTS devices can be used to control the power flow and enhance system stability. They are playing an increasing and major role in the operation and control of power systems. The UPFC (Unified Power Flow Controller) is the most versatile and powerful FACTS device [1]. The parameters in the transmission line, i.e. line impedance, terminal voltages, and voltage angle can be independently controlled by UPFC. It is used for independent control of real and reactive power in transmission lines. Moreover, the UPFC can be used for voltage support and damping of electromechanical oscillations [2~4]. Damping of electromechanical oscillations due to sudden change in input mechanical power, faults etc. is necessary for secure system operation [5]. In this paper, researches are based on single machine system with UPFC. A well-designed UPFC controller can not only increase the transmission capability but also improve the power system stability.

A series of approaches have been made in developing damping control strategy for UPFC. The coordination between FACTS controllers and other power system controllers is very important and is presented in this paper by Fuzzy-coordination. The fuzzy logic controllers are rule-based controllers in which a set of rules represents a control decision mechanism to adjust the effect of certain cases coming from power system. Furthermore, fuzzy logic controllers do not require a mathematical model of the system [10]. This paper focuses on the optimization of conventional power oscillation damping (POD) controllers and fuzzy logic coordination of them. By using fuzzy-coordination controller, the coordination objectives of the FACTS devices are quite well achieved.

Few researchers have presented a linearised Heffron-Phillips model of a power system installed with UPFC in order to design suitable controllers for power flow, voltage and damping controls. Wang [6~8] has addressed the basic issues pertaining to the design of damping controller using UPFC. Application of Genetic Algorithm technique is implement in this paper for designing UPFC based damping controllers.

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- To present a systematic approach for designing Genetic Algorithm based UPFC damping controller using UPFC shunt converter (exciter) phase angle (δ_E). To examine the relative effectiveness of UPFC damping controller (δ_E) for damping power system oscillations.
- To compare the performance of UPFC based damping controllers:
  1. Without Genetic Algorithm technique
  2. With Genetic Algorithm technique
- To investigate the performance of this damping controller, following wide variations in loading conditions and system parameters

II. SYSTEM UNDER STUDY

The system used in the investigations of this paper (Figure 1) consists of a synchronous generator which is connected via two transformers to an infinite bus system through a transmission line. A UPFC is installed in the midpoint of the transmission line [7]. The system dynamic model is used to represent and study the dynamic performance of the single-machine infinite-bus power system. The UPFC considered here is assumed to be based on pulse width modulation (PWM) converters. The nominal loading condition and system parameters are given in Appendix – 1.

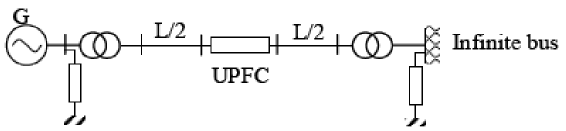

Fig. 1 Single Machine Infinite Bus Power System

III. THE UNIFIED PHILIPS HEFFORN MODEL OF THE POWER SYSTEM INSTALLED WITH UPFC

Unified power flow controller (UPFC) is a combination of static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) which are coupled via a common dc link to allow bi-directional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source [9]. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance and angle or alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation. By controlling δ_E, the dc voltage of dc link can be regulated. Figure 2 shows a single-machine infinite-bus power system equipped with a UPFC [7]. m_B, m_E and δ_B ,δ_E are the amplitude modulation ratio and phase angle of the control signal of each voltage source converter respectively, which are the input control signals of the UPFC.

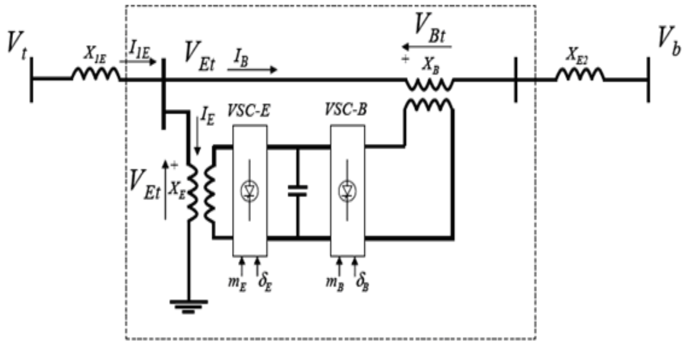

Fig 2. A UPFC installed in a single-machine infinite-bus

The non-linear differential equations from which the well known Phillips-Heffron linear model of a single-machine infinite-bus power system is derived are:

$$\overset{o}{\delta} = \omega_o \Delta\omega$$

$$\Delta \overset{o}{\omega} = (P_m - P_e - D\Delta\omega)/2H$$

$$\overset{o}{E}{}'_q = (-E_q + E_{qe})/T'_{do}$$

$$\overset{o}{E}{}'_{qe} = reg(s)(v_{to} - v_t)$$

(1)

A linearized model of the power system can be used in studying power system oscillation stability and control [6~7]. For the study of power system oscillation stability, the resistance and transient of the transformers of the UPFC can be ignored. The dynamic equations of the UPFC can be written as:

$$\begin{bmatrix} v_{Etd} \\ v_{Etq} \end{bmatrix} = \begin{bmatrix} 0 & -X_E \\ X_E & 0 \end{bmatrix} \begin{bmatrix} i_{Ed} \\ i_{Eq} \end{bmatrix} + \begin{bmatrix} \frac{m_E v_{dc} \cos(\delta_E)}{2} \\ \frac{m_E v_{dc} \sin(\delta_E)}{2} \end{bmatrix}$$

$$\begin{bmatrix} v_{Btd} \\ v_{Btq} \end{bmatrix} = \begin{bmatrix} 0 & -X_B \\ X_B & 0 \end{bmatrix} \begin{bmatrix} i_{Bd} \\ i_{Bq} \end{bmatrix} + \begin{bmatrix} \frac{m_B v_{dc} \cos(\delta_B)}{2} \\ \frac{m_B v_{dc} \sin(\delta_B)}{2} \end{bmatrix}$$

$$\frac{dv_{dc}}{dt} = \frac{3m_E}{4C_{dc}}[\cos(\delta_E)\ \sin(\delta_E)] \begin{bmatrix} i_{Ed} \\ i_{Eq} \end{bmatrix} + \frac{3m_B}{4C_{dc}}[\cos(\delta_B)\ \sin(\delta_B)] \begin{bmatrix} i_{Bd} \\ i_{Bq} \end{bmatrix}$$

(2)

By combining and linearizing Equations (2) UPFC and single machine infinite bus power system (1), the state variable equations of the power system equipped with the UPFC can be represented by equation (3). Figure 3 shows the small perturbation transfer function block diagram of a machine-infinite bus system including UPFC relating the pertinent variables of electric torque, speed, angle, terminal voltage, field voltage, flux linkages [7]. This linear model has been developed by linearising the nonlinear differential equations around a nominal operating point.

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$$\begin{bmatrix}\overset{o}{\Delta\delta}\\ \overset{o}{\Delta\omega}\\ \overset{o}{\Delta E_q'}\\ \overset{o}{\Delta E_{qe}}\end{bmatrix} = \begin{bmatrix} 0 & \omega_o & 0 & 0\\ -\frac{K1}{M} & -\frac{D}{M} & -\frac{K2}{M} & 0 \\ -\frac{K_4}{T_{do}'} & 0 & \frac{K_3}{T_{do}'} & \frac{1}{T_{do}'}\\ -\frac{K_AK_5}{T_A} & 0 & -\frac{K_AK_6}{T_A} & -\frac{1}{T_A}\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta\omega\\ \Delta E_q'\\ \Delta E_{qe}\end{bmatrix} + \begin{bmatrix}0\\ -\frac{K_{pd}}{M}\\ -\frac{K_{qd}}{T_{do}'}\\ -\frac{K_AK_{vd}}{T_A}\end{bmatrix}\Delta V_{dc}$$

$$+\begin{bmatrix} 0 & 0 & 0 & 0\\ -\frac{K_{Pe}}{M} & -\frac{K_{p\delta e}}{M} & -\frac{K_{pb}}{M} & -\frac{K_{p\delta b}}{M}\\ -\frac{K_{qe}}{T_{do}'} & -\frac{K_{q\delta e}}{T_{do}'} & -\frac{K_{qb}}{T_{do}'} & -\frac{K_{q\delta b}}{T_{do}'}\\ -\frac{K_AK_{ve}}{T_A} & -\frac{K_AK_{v\delta e}}{T_A} & -\frac{K_AK_{vb}}{T_A} & -\frac{K_AK_{v\delta b}}{T_A}\end{bmatrix}\begin{bmatrix}\Delta m_E\\ \Delta\delta_E\\ \Delta m_B\\ \Delta\delta_B\end{bmatrix} \quad (3)$$

where Δm_E $\Delta\delta_E$ Δm_B $\Delta\delta_B$ are the deviation of input control signals of the UPFC.

Block diagram in figurfe 3 can be used in small signal stability investigations of the power system. The MATLAB Simulink toolbox can be used to study the system performance under different disturbances.

$$\Delta f = [\Delta v_{dc} \quad \Delta m_E \quad \Delta\delta_E \quad \Delta m_B \quad \Delta\delta_B]$$

$$Kp = \begin{bmatrix}\frac{K_{pd}}{M} & \frac{K_{pe}}{M} & \frac{Kp_{\delta e}}{M} & \frac{K_{pb}}{M} & \frac{K_{p\delta b}}{M}\end{bmatrix}$$

$$Kq = \begin{bmatrix}\frac{K_{qd}}{T_{do}'} & \frac{K_{qe}}{T_{do}'} & \frac{K_{q\delta e}}{T_{do}'} & \frac{K_{qb}}{T_{do}'} & \frac{K_{q\delta b}}{T_{do}'}\end{bmatrix}^T$$

$$Kv = \begin{bmatrix}\frac{K_AK_{vd}}{T_A} & \frac{K_AK_{ve}}{T_A} & \frac{K_AK_{v\delta e}}{T_A} & \frac{K_AK_{vb}}{T_A} & \frac{K_AK_{v\delta b}}{T_A}\end{bmatrix}^T \quad (4)$$

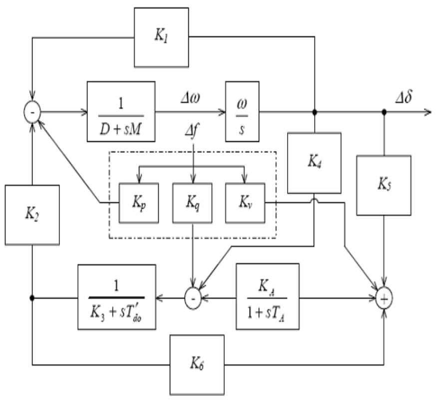

Fig 3. Heffron-Phillips model of SMIB system with UPFC

IV. SIMPLE GENETIC ALGORITHM

Genetic algorithms are different from normal search methods encountered in engineering optimization in the following ways [11]:

1- GA work with a coding of the parameter set not the parameters themselves.

2- GA search from a population of points, not a single point.

3- GA use probabilistic transition rules, not deterministic transition rules.

A typical GA search starts with a random population of individuals. Each individual (a string) is a coded set of parameters that we want to optimize. An objective (fitness) function is used to determine how fit these individuals are. A suitable selection strategy is employed to select the individuals that will reproduce. Reproduction (or a new set of individuals) is achieved by using crossover and mutation operators. The GA then manipulates the most promising strings in its search for improved solutions. A GA operates through a simple cycle of stages as follows [23]:

1- Creation of a "population" of strings (using a random generator).

2- Evaluation of each string (using a fitness function).

3-Selection of best strings (using a suitable selection method).

4-Genetic manipulation to create the new population of strings

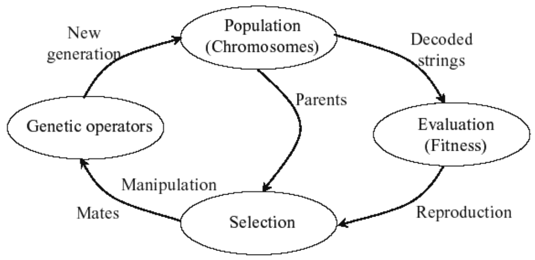

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Fig 4. GA Cycle

Several practical means of deciding when to stop regeneration are used. These are [24]:

1- Stop after a period of time (Maximum number of generations).

2- Stop when the average fitness is close to the minimum (or the maximum) of the fitness.

3- Stop when there is no improvement in the maximum (or minimum) value of the fitness.

4- Stop after finding a better solution than the one proposed by other means or criterion.

5- Stop after finding the desired maximum (or minimum).

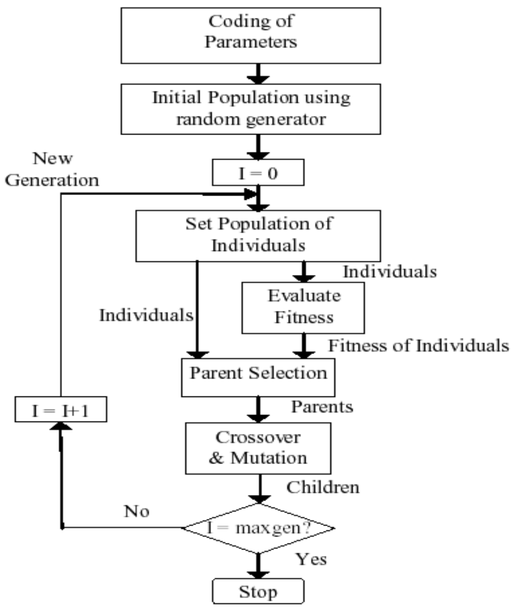

Fig 5 GA Flow Chart

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V.MODEL OF SMIB EQUIPPED WITH UPFC & GA BASED DAMPING CONTROLLER

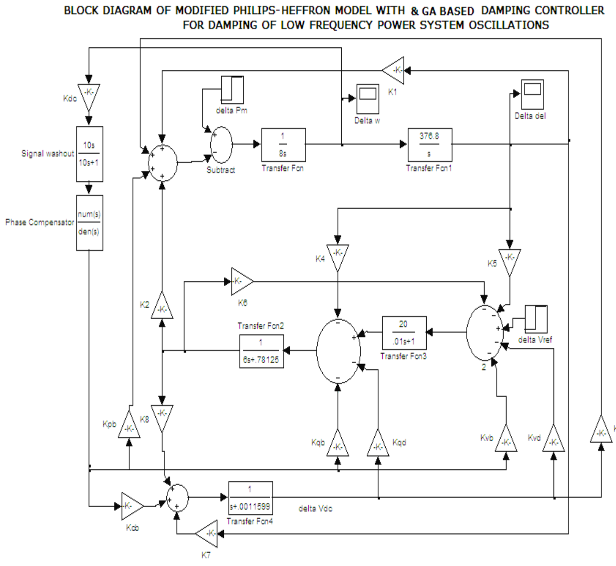

Fig 6 Modified Phillips-Heffron Model of SMIB with UPFC & GA based damping controller

VI. DATA AND RESULT

The K - constants of the model computed for nominal operating condition of Single Machine Infinite Bus System equipped with UPFC are given in Table I:

Table I: K-constants for UPFC controller δ_E

K-Constant	Pe=0.77 Qe=0.1599	Pe=0.47 Q=0.075	Pe=0.18 Q=0.0098
K_1	0.40929	0.46312	0.47958
K_2	0.34496	0.25353	0.1397
K_3	0.78125	0.78125	0.78125
K_4	0.41736	0.283	0.11571
K_5	0.11844	0.09101	0.04433
K_6	0.36219	0.3669	0.37235
K_7	0.40399	0.40399	0.40399
K_8	0.04572	0.04572	0.04572
K_9	0.001159	0.00115	0.00116
$K_{p\delta e}$	0.852	0.8010	0.77183
$K_{q\delta e}$	-.070521	-0.0705	-0.0705
$K_{v\delta e}$	0.074972	0.06184	0.04005

A. Constants & Dynamic Responses of GA based Damping Controller

GEPA	|GEPA|	∠GEPA	∠Gc	∠Gc + ∠GEPA
$\Delta Pe/\Delta\delta E$	0.80353	2.3449 °	-2.346°	-0.00119

Damping Controller Type	*Kdc*	*T1*, s	*T2*, s
Damping controller (δ_E)	45.9770	0.22837	0.23263

B. Dynamic responses:

Fig7.1, Fig.7.2, Fig.7.3 shows the comparison of Δδ dynamic responses obtained for 0.01 step change in mechanical power input P_m to SMIB. These dynamic responses are obtained using Matlab Simulink for different values of K obtained at variable loading conditions mentioned above

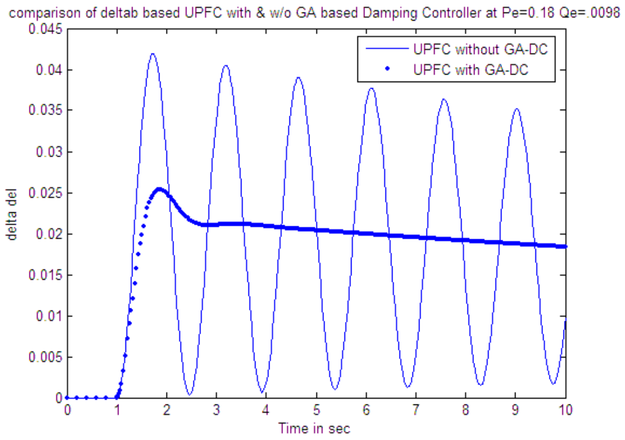

Fig.7.1 Dynamic response of UPFC controller (δ_E) with & without GA based Damping Contrller at Pe = 0.18 Qe = 0.0098

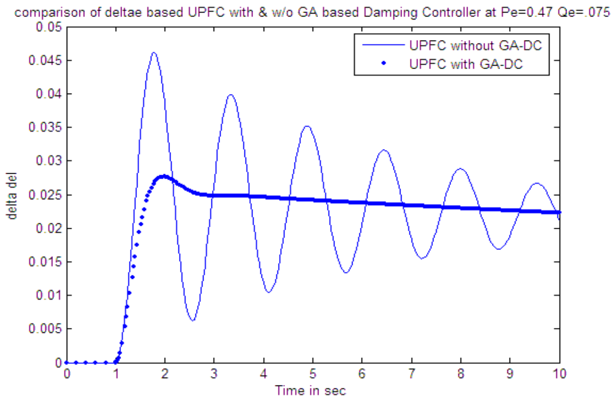

Fig. 7.2 Dynamic response of UPFC controller (δ_E) with & without GA based Damping Contrller at Pe = 0.18 Qe = 0.0098

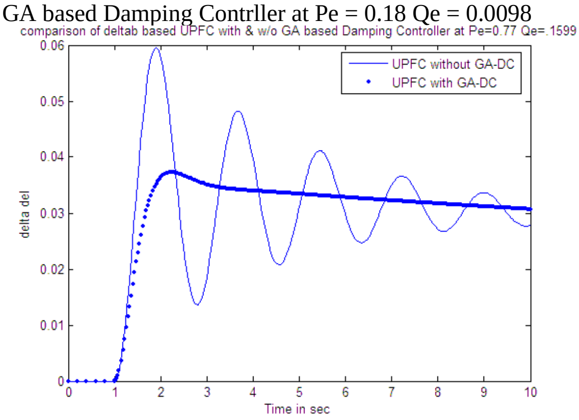

Fig. 7.3 Dynamic response of UPFC controller (δ_E) with & without GA based Damping Contrller at Pe = 0.18 Qe = 0.0098

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VI. CONCLUSION

The significant contributions of the research work presented in this paper are as follows:

1. A systematic approach for designing proportional Genetic Algorithm - UPFC based damping controllers for damping power system oscillations has been presented.
2. The performance of the UPFC damping controller (δ_E) has been examined considering wide variation in the loading conditions.
3. Investigations reveal that the UPFC damping controller (δ_E) provides robust performance to wide variation in loading conditions. The performance of controller improves as the loading increases. It may thus be recommended that the Genetic Algorithm controlled damping controller based on UPFC control parameters δ_E may be preferred damping low frequency power system oscillations.

Appendix-1

The nominal parameters and the operating condition of the system are given below.

Power System data : Tdo = 5.044 s Xd = 1.0 pu Xq = 0.6 pu $X'd$ = 0.3 pu $M = 2H$ = 8.0 MJ/MVA D = 0.0 Ka = 100 Ta = 0.01 s

Operating condition : Vt = 1.0 pu Vb = 1.0 pu

f = 50 Hz

REFERENCES

1. A Nabavi-Niaki and M R Iravani., "Steady-state and Dynamic Models of Unified Power Flow Controller (UPFC) for Power System Studies," *IEEE Transactionson Power Systems*, vol 11, no 4, November 1996, p 1937.
2. K S Smith, L Ran and J Penman, "Dynamic Modelling of a Unified Power Flow Controller," *IEE Proceedings-C*, vol 144, no 1, January 1997, p 7.
3. T Makombe and N Jenkins. "Investigation of a Unified Power Flow Controller," *IEE Proceedings-C*, vol 146, no 4, July 1999, p 400.
4. Papic and P Zunko *et al*. "Basic Control of Unified Power Flow Controller," *IEEE Transaction on Power Systems*, vol 12, no 4, November 1997, p 1734.
5. Y Morioka and Y Nakach, *et al*. "Implementation of Unified Power Flow Controller and Verification for Transmission Capability Improvement," *IEEETransactions on Power Systems*, vol 14, no 2, May 1999, p 575.
6. H F Wang. "Damping Function of Unified Power Flow Controller," *IEE Proceedings-C*, vol 146, no 1, January 1999, p 81.
7. H. F. Wang, F. J. Swift, "A Unified Model for the Analysis of FACTS Devices in Damping Power System Oscillations Part I: Single-machine Infinite-bus Power Systems," *IEEE Transactionson Power Delivery, Vol. 12, No. 2*, April, 1997, pp. 941-946.
8. H. F. Wang, F. J. Swift, "A Unified Model for the Analysis of FACTS Devices in Damping Power System Oscillations Part II: Multi-machine Power Systems," *IEEE Transactions on Power Delivery, Vol. 13, No. 4*, October, 1998, pp. 1355-1362.
9. NarainG.Hingorani,andLaszloGyugyi,*UNDERSTANDING FACTS*. IEEE Press, New York, 2000.
10. Hao Ying, "*Fuzzy Control and Modeling: Analytical Foundations and Applications*, IEEE Press Series on Biomedical Engineering, Series Editor: Metin Akay, New York, 2000.
11. Jong-Bae Park, Young-Moon Park, Jong-Ryul Won, and Kwang Y. Lee, "An Improved Genetic Algorithm for Generation Expansion Planning", *IEEE Transactions on power Systems*, Vol.15,No.3,August 2000 pp 365-371

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