THE COORDINATION BETWEEN UNIFIED POWER FLOW CONTROLLER(UPFC)AND POWER SYSTEM STABILIZER(PSS) FOR ENHANCING POWER SYSTEM STABILITY

التنسيق بين جهاز التحكم الموحد لتدفق القدرة(UPFC) ومضبط منظومة القدرة (PSS) لتحسين استقرارية منظومة القدرة

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المستخلص

الهدف الرئيسي من هذا البحث هو دراسة كفاءة التصميم المنسق لمظبط منظومة القدرة (PSS) والمظبط المستند على المدخل (m_B) لجهاز التحكم الموحد لتدفق القدرة (UPFC) في تحسين استقرارية منظومة القدرة . وتم صياغة مسالة التصميم للمسيطرات بشكل مسالة الحل الامثل. با ستخدام النموذج الخطي المطور لمنظومة القدرة المجهزة بجهاز التحكم لتدفق القدرة الموحد ومظبط منظومة القدرة وتم استخدام امثلية سرب الجسيمات(PSO) للبحث عن افضل القيم لمكونات المسيطرات.التصميم المنسق للمسيطرات تم تطبيقه على منظومة ذات ماكنة واحدة وموصل عمومي لامتناهي مجهز بجهاز التحكم الموحد لتدفق القدرة وبينت القيم الذاتية(المميزة) والمحاكاة الزمنية الغير خطية فعالية التصميم المنسق في تعزيز استقرارية منظومة القدرة .

Abstract

The main objective of this study is to investigate the enhancement of the power system stability via coordinated design of the Power System Stabilizer (PSS) and m_B-based stabilizer of unified power flow controller (UPFC). The

design problem of PSS and m_B-based stabilizer are formulated as an optimization problem. Using the developed linearized model of a power system equipped with UPFC & PSS, the particle swarm optimization (PSO) algorithm is employed to search for optimal controllers parameters.. The proposed controllers are evaluated on a single machine infinite bus power system with UPFC installed. The nonlinear time domain simulation and eigenvalues analysis results show the effectiveness of the coordinated design in enhancing the power system stability.

1. INTRODUCTION

the power demand has grown rapidly and, therefore, the need for more complex power systems has arisen . on the other hand Expansion and generation is restricted with the limited availability of resources and the strict environmental constraints .as a result, power systems are today more loaded than before, causing the systems to operate near their transient stability limits. Furthermore, interconnection between distantly located power systems is now a common practice, which gives rise to low frequency oscillations in the range of 0.1-3.0 Hz. If not well damped, these oscillations may keep growing in magnitude until loss of synchronism results.

Power system stability is one of the main concerns in the power system operation since many years [1-2].Power system stabilizers (PSSs) have been used in the last few decades to serve the purpose of enhancing power system damping of low frequency oscillations. PSSs, which operate on excitation system of generators have proved to be efficient in performing their assigned tasks. Nowadays, the conventional power system stabilizer (CPSS) is widely used by power utilities.

Generally, it is important to recognize that machine parameters change with loading making the machine behavior quite different at different operating conditions.

Hence, PSSs should provide some degree of robustness to the variations in system parameters, loading conditions, and configurations. H_∞ optimization techniques [3] have been applied to robust PSS design problem. However, the order of the H_∞ based stabilizer is as high as that of the plant. This gives rise to complex structure of such stabilizers as reduces their applicability.

A comprehensive analysis of the effects of the different CPSS parameters on the dynamic performance of the power system was presented in [4]. It is shown that the CPSS provide satisfactory damping over a wide range of system loading conditions [5]. Although PSSs provide supplementary feedback stabilizing signals, they suffer a drawback of being liable to cause great variations in the voltage profile.

The recent advances in power electronics have led to the development of the flexible alternating current transmission systems (FACTS). Utilities are beginning to install FACTS devices in their transmission networks due to the increase in the power system requirements. It is well recognized that FACTS devices, in addition to their primary function, have the capability of enhancing the system stability[6].

A unified power flow controller (UPFC) is the most promising device in the FACTS concept, It has the ability to adjust the three control parameters, i.e. the bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently. A UPFC performs this through the control of the in-phase voltage, quadrature voltage, and shunt compensation.Till now, not much research has been devoted to the analysis and control of UPFCs.A UPFC can control the three control parameters either individually or appropriate combinations at series-connected output while maintaining reactive power support at its shunt –connected input.[7].through the use of a SIMB

system investigated the mechanism of the three control methods of a UPFC in enhancing power system damping, It was shown that a significant reduction in the transient swing can be obtained with any of the three methods by using a simple proportional feedback of machine rotor angle deviation.[8]

High frequency power fluctuations, more than 100 Hz, induced by a UPFC have been the investigated in [9]..Its is generally accepted that the addition of a supplementary controller to the UPFC device can significantly enhance power system stability .

Due to their interesting characteristics, PSS-and UPFC may be incorporated simultaneously in the power system to improve its transient performance However, the interaction among these controllers needs to be considered in the controller design stage as one controller may adversely affect the performance of the others. Therefore, coordinated design between PSSs and UPFC is a necessity, both to make use of the advantages of different stabilizers and to avoid the demerits accompanied with their operations.

In this paper, a comprehensive assessment of the effects of robust controller design of the Excitation and unified power flow controller when they applied independently and also through coordinated application has been carried out. The design problem is transformed into an optimization problem where the particle swarm optimization (PSO) algorithm is employed to search for the optimal settings of stabilizers' parameters. A controllability measure based on singular value decomposition (SVD) is used to identify the effectiveness of each controller input. For completeness, the eigenvalue analysis and nonlinear simulation results are carried out to demonstrate the effectiveness and robustness of the proposed stabilizers to enhance system stability. The objective of this thesis to investigate the effectiveness of the

coordinated design of power system stabilizers and UPFC to improve system transient stability. All the simulations are carried out using MATLAB and SIMULINK packages

2 - POWER SYSTEM MODEL

in this study, a single machine infinite bus system(SMIB) with UPFC is considered as shown in figure 1.

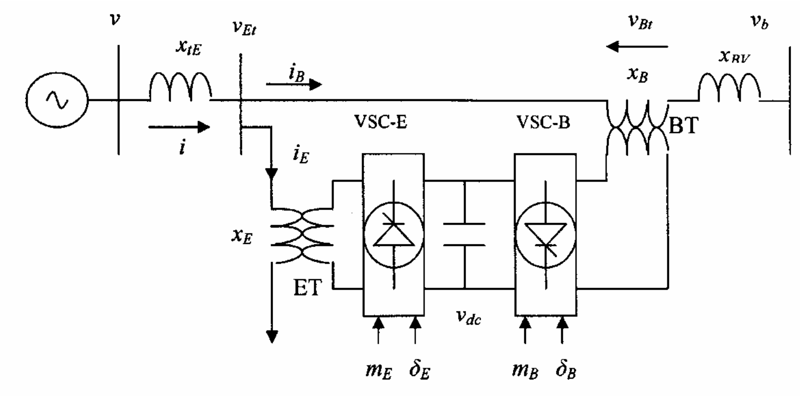

Figure 1: single-machine infinite-bus (SMIB)with a UPFC[10]

2.1 Generator model

The generator is represented by the 3rd order model consisting of the swing equation and the generator internal voltage equation can be written as

$$\dot{\delta} = \omega_b (\omega - 1) \quad (1.1)$$

$$\dot{\omega} = (p_m - pe - D(\omega - 1)/M \quad (1.2)$$

$$\dot{E}q = (E_{fd} - (x_d - x'_d) i_d - E'_q)/T'_{do} \quad (1.3)$$

The real power output of the generator is described as

$$Pe = v_d \, i_d + v_q i_q \quad (1.4)$$

$$V_d = x_q i_q$$

$$v_q = E'_q - x'_d i_d$$

Where, p_m and p_e are input and output power of the generator respectively; M and D are the inertia constant and damping coefficient respectively; δ and ω are rotor angle and speed respectively; E_{fd} is the field voltage; V_d and V_q are d- and q-axis armature voltage; i_d and iq

d- and q-axis armature current T'_{do} is the open circuit field time constant, x_d and x'_d are the d-axis reactance and d-axis transient reactance of the generator respectively

2.2 Exciter and PSS

The excitation system can be represented by the IEEE type-ST1 system shown in figure2, is considered .it can be described as:

$$\dot{E}fd = (kA(Vref - v + upss) - Efd)/T_A$$ (1.5)

$$v^2 d \quad + \quad v^2 q \quad)^{1/2}$$ (1.6)$(V=$

Where, K_A and T_A are the gain and time constant of the excitation system respectively; V_{ref} is the reference voltage. As shown in Fig. 2, a conventional lead-lag PSS is installed in the feedback loop to generate a stabilizing signal u_{PSS}.

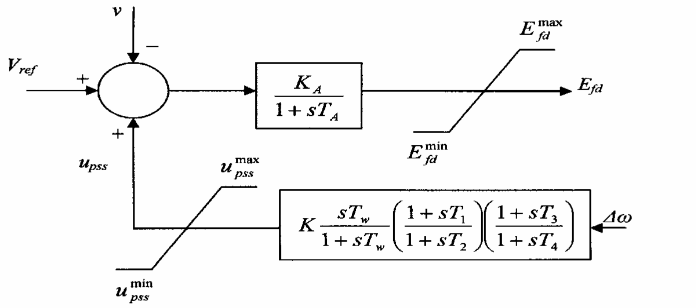

Figure 2:IEEE type-ST1 excitation system with PSS

2.3 Unified power flow controller (UPFC) model

The UPFC cosists of a shunt-connected excitation transformer (ET),a series connected boosting transformer (BT), two three-phase GTO based voltage source converters (VSCs), and acommon DC link capacitors, see figure (1-1) The four input control signals to the UPFC are m_B , m_E , δ_E, and δ_B. where m_B , m_E are boosting and excitation amplitude modulation ratios , δ_B and δ_E are boosting and excitation phase angles modulation.

The series converter is controlled to inject a boosting voltage, v_{Bt}, in series With the line. The magnitude of v_{Bt} can be varied from 0 to $v_{Bt,max}$ and the angle can be vaied independently from 0 to 360 degree.

The main function of the shunt converter is to supply the real-power demand to the series converter. It also plays the role of regulating the terminal of the interconnected bus by controlling the reactive power supply/demand to that bus.[10]

By applying park's transformation and neglecting the resistance and transients of the ET and BT transformers, the UPFC can be modeled as [11]:

$$\begin{pmatrix} V_{Etd} \\ V_{Etq} \end{pmatrix} = \begin{pmatrix} 0 & -X_E \\ X_E & 0 \end{pmatrix} \begin{pmatrix} i_{Eq} \\ i_{Eq} \end{pmatrix} + \begin{pmatrix} \frac{m_E \cos\delta_E \, v_{dc}}{2} \\ \frac{m_E \sin\delta_E \, v_{dc}}{2} \end{pmatrix} \quad (1.7)$$

$$\begin{pmatrix} V_{Btd} \end{pmatrix} = \begin{pmatrix} 0 & -X_B \end{pmatrix} \begin{pmatrix} i_{Bd} \end{pmatrix} + \begin{pmatrix} \frac{m_B \cos\delta_B \, V_{dc}}{2} \end{pmatrix}$$

(1.8)

V_{Btq} X_B 0 $\dot{i}_{Bq}$

$m_B \sin\delta_B V_{dc}$

2

(1.9) $3m_E$ $\dot{i}_{Ed}$ $3m_B$

$V_{dc} =$ $[\ \cos\delta_E \quad \sin\delta_E\ ] +$ $[\cos\delta_B$

$\sin\delta_E]$ $4C_{dc}$

$4C_{dc}$

$\dot{i}_{Eq}$

$\dot{i}_{Bq}$

where *VEt* , *iE* are excitation voltage and current , *VBt* , *iB* are boosting voltage and current ,*Cdc*, *Vdc* are DC link capacitance and voltage X_E, *XB* are ET and BT reactances

The UPFC damping controllers are of the structure shown in figure 3, where u can be, m_B, δ_B m_E, or δ_E

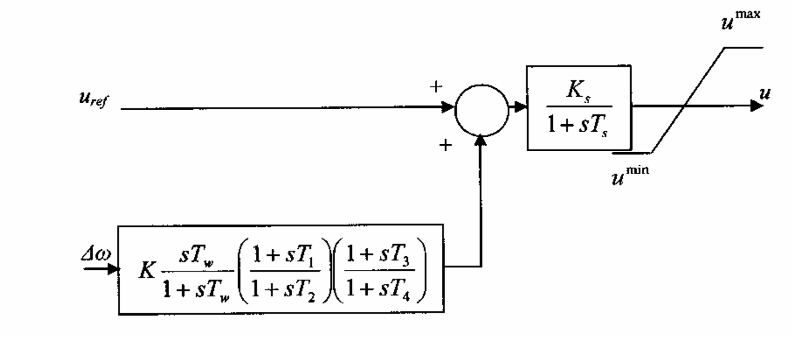

Figure 3:UPFC with lead-lag controller

2.4 Linearized Model

In the design of electromechanical mode damping controllers, the linearized incremental model around a nominal operation point is usually employed [1].

where K_1-K_9, K_{Pd}, K_{pe}, K_{Pde}, K_{pb}, K_{Pdb}, K_{qd}, K_{qe}, K_{qde}, K_{qb}, K_{qdb} , $K_{v\ d}$,K_{ve} ,K_{vde} , K_{vd}, K_{vdb}, K_{ce},K_{cde},K_{cb} and K_{cdb} are

linearization constants .In state-space representation, the power system can be modeled as:

$$\Delta \dot{X} = A\Delta X + B\Delta U \quad (1.10)$$

where

$$\Delta X = [\Delta\delta \quad \Delta\omega \quad \Delta \grave{E}q \quad \Delta E_{fd} \quad \Delta Vdc]^{T}$$

$$\Delta U = [\Delta Upss \quad \Delta m_E \quad \Delta\delta_E \quad \Delta m_B] \quad \Delta\delta_B^{\;T}$$

$$A = \begin{pmatrix} 0 & \omega b & 0 & 0 & 0 \\ \frac{K1}{M} & -\frac{D}{M} & -\frac{K2}{M} & 0 & -\frac{KPd}{M} \\ -\frac{K4}{T'do} & 0 & -\frac{K3}{T'do} & \frac{1}{T'do} & -\frac{Kqd}{T'do} \\ -\frac{KAK5}{TA} & 0 & -\frac{KAK6}{TA} & -\frac{1}{TA} & -\frac{KAKvd}{TA} \\ K7 & 0 & K8 & 0 & -K9 \end{pmatrix}$$

$$B = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{K_{pe}}{M} & -\frac{K_{p\delta e}}{M} & -\frac{K_{pb}}{M} & -\frac{K_{p\delta b}}{M} \end{pmatrix}$$

$$\begin{array}{ccccc} 0 & -\frac{K_{qe}}{T'_{do}} & -\frac{K_{q\delta e}}{T'_{do}} & -\frac{K_{qb}}{T'_{do}} \quad 0 & -\frac{K_{q\delta b}}{T'_{do}} \\ \underline{K_A} & -\underline{K_A K_{ve}} & -\underline{K_A K_{v\delta e}} & -\underline{K_A K_{vb}} & -\underline{K_A K_{v\delta b}} \end{array}$$

T_A	T_A	T_A	T_A	T_A
0	K_{ce}	$K_{c\delta e}$	T_{cb}	$T_{c\delta b}$

2.5 The system parameters

the parameters of the system used in optimization results of the UPFC are:

Machine: $xd = 1$; $xq = 0.6$;$x'd = 0.3$;$D = 0$;$M = 8.0$; $T'do = 5.044$;$fred = 60$;$v = 1.05$;

Exciter: $K_A = 50$; $T_A = 0.05$; $E_{fd\_max} = 7.3$; $E_{fd\_man} = -7.3$;

PSS: $Tw = 5$; $T_{i\_min} = 0.01$; $T_{i\_max} = 5.0$; i= 1,2,3,4; $u_{pss\_max} = 0.2$; $u_{pss\_min} = -0.2$;

DC voltage regulator: $K_{dp} = -10$;$k_{di} = 0$;

Transmission line: $x_{tE} = 0.1$; $x_{Bv} = 0.6$;

UPFC: $x_B = 0.1$; $x_E = 0.1$ $Ks = 1$;$Ts = 0.05$; $C_{dc} = 3$; $V_{dc} = 2$;$m_{E\_max} = 1$;$m_{E\_min} = 0$;

$m_{B\_max} = 1$;$m_{B\_min} = 0$.

3.The proposed approach

3.1 Electromechanical mode identification

The state equations of the linearized model can be used to determine the eigenvalues of system matrix A. out of these eigenvalues ;there is a mode of oscillations related to machine inertia .for the stabilizers to be effective ,it is extremely important to identify .The eigenvalue associated with the electromechanical mode. in this study ,the participation factors method is used[12,13]

3.2 Problem Formulation.

To select the best stabilizer parameters that enhance most the power system transient performance ,eigenvalue-based objective function is proposed:

J=min{ ζ_i : ζ_i is a vector of the damping ratios corresponding to all the complex eigenvalues of the system at the *i*th loading condition.

This objective function will identify the minimum value of damping ratio among electromechanical modes of the loading condition considered in the design process. The design problem can be formulated as the following optimization problem format.

Optimize J

Subject to

$K^{min} \leq K \leq K^{max}$

$T_1^{min} \leq T_1 \leq T_1^{max}$

$T_2^{min} \leq T_2 \leq T_2^{max}$

$T_3^{min} \leq T_3 \leq T_3^{max}$

$T_4^{min} \leq T_4 \leq T_4^{max}$

The minimum and maximum value of the controller gains is set as 0.1 and 100 respectively. The minimum and maximum values of T_1 , T_2, $T_3$and T_4 are set as 0.1 and 5.0s. respectively.

3.3Application of PSO Algorithm

Based on the linearized power system model in equation (10), Particle Swarm Optimization (PSO) [14,15] has been applied to the above optimization problem to search for optimal settings of the proposed stabilizer.

In this study, the UPFC and PSS controllers' parameters are optimized at nominal loading (Pe,Qe)=(1.0,0.015)pu of operating conditions

The final Setting of the optimized parameters for the proposed stabilizers are given in Table 1.

Table 1: optimal settings of the controller parameters

	Individual		Coordinated	
	PSS	m_B	PSS	m_B
K	16.9203	29.062	40.336	72.954
T_1	4.5673	2.8973	1.5852	0.1163
T_2	2.0440	0.9339	2.0945	0.0100
T_3	0.0835	0.1039	4.7773	0.1130
T_4	0.0100	0.0100	5.0000	0.0100

4.SIMULATION RESULTS

To assess the effectiveness of the proposed stabilizers, two different loading conditions given in table(2) below

Table(2):loading conditions

Pe(pu)	Qe(pu)	loading
1.0	0.015	1.nominal loading
0.3	0.015	2.light loading

4.1Eigenvalue Analysis:

The system eigenvalues without and with the Proposed PSS and m_B-based controllers when applied individually and

through Design at the two loading conditions, nominal, light, are Given in Tables 3-4, respectively. The bold rows of these tables represent the EM mode eigenvalue and its damping ratio. It is evident that, using the Proposed coordinated stabilizers design, the damping ratio of the EM mode .Eigenvalue is greatly enhanced. Hence, it can be concluded that this well improves The system stability.

Table 3: System eigenvalues of nominal loading conditions

No Control	PSS	m_B	PSS & m_B
1.5033± 5.3328i,	**-4.7000± 6.8700i,**	**-41000± 6.0700i,**	**-7.1317± 6.8248i,**
-0.2713	**0.5600**	**0.5600**	**0.7200**
-11.4584±6.8596i	-4.8700±7.0400i	-4.2000±6.2400i	-7.2300±6.8000i
-15.5063	-101.12	-93.980	-101.83±69.950i
-5.1052	-15.340	-28.950	-15.290
--	-4.8700	-15.530	-8.4600
--	-0.5500	-51300	-4.4100
--	--	-1.4000	-0.4500
--	--	--	-02100
--	--	--	-0.2100

Table 4: System eigenvalues of litgh loading conditions

No Control	PSS	m_B	PSS & m_B
1.3952± 5.0825i,	**0.2800± 5.500i,**	**-3.2300± 6.4500i,**	**-2.0487± 4.4154i,**
-0.2647	**-0.0500**	**0.4500**	**0.4200**
-11.3641± 6.1234i,	-9.8300± 6.3400i	-5.0400± 4.8700i	-10.050± 9.8000i
-15.5063	-101.12	-93.980	-101.83± 69.950i
-5.1052	-15.340	-28.950	-15.290
--	-4.8700	-15.530	-8.4600
--	-0.5500	-5.1300	-4.4100
--	--	-1.4000	-0.4500
--	--	--	-0.2100
--	--	--	-0.2100

4.2 Non Linear Time Domain Simulation

The single machine infinite bus system shown in Fig. 1 is considered for nonlinear simulation studies. 6-cycle 3-φ fault on the infinite bus was created, at all loading conditions given in Table 3, to study the performance of the proposed controller.

Figures 4-5 show the rotor angle, the speed deviation response with above mentioned disturbance at nominal and light loading conditions respectively.

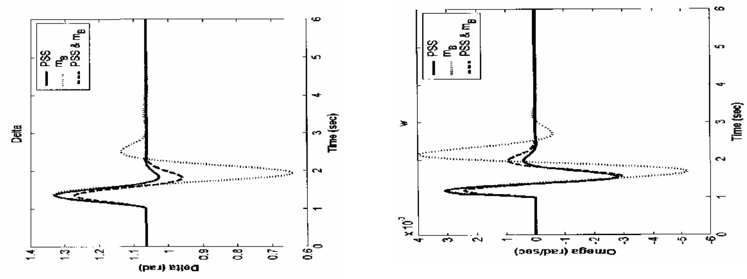

Figure 4:machine rotor angle and speed response for a six cycles fault with nominal loading condition

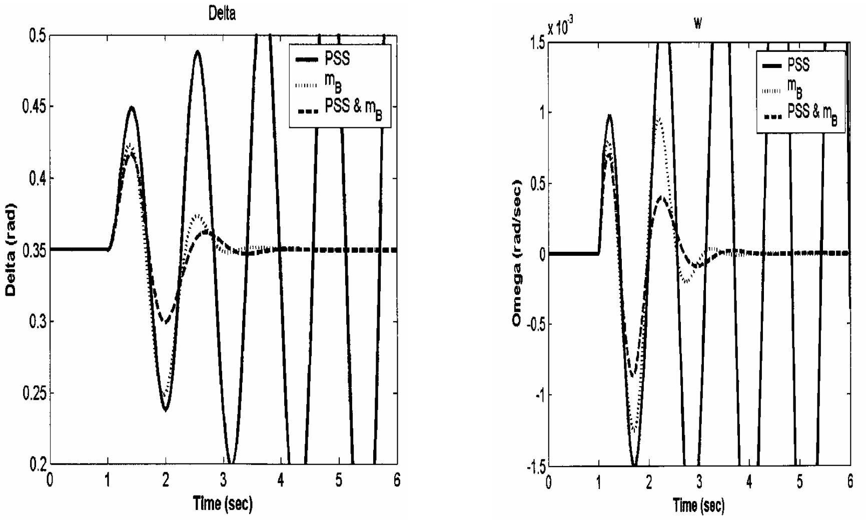

Figure 5:machine rotor angle and speed response for a six cycles fault with light loading condition

4.3 conclusion

From the eigenvalue analysis and the non linear time domain simulation can be concluded the following:

1. **It is clear from the eigenvalues analysis that the system stability is greatly enhanced with the proposed stabilizer.**
2. **It can be also seen that the coordinated design outperforms the individual design at two points considered in the sense that the damping ratio of the electromechanical modes at two points are greatly**
3. **Form the figures 4-5 it can be seen that the coordinated design approach provides the best damping characteristic and enhance greatly the first swing stability at all loading conditions.**

REFERENCES

[1] Y. N. Yu, Electric Power System Dynamics, Academic Press, 1983.

[2] F. deMello and C. Concordia, “Concepts of Synchronous Machine Stability as Affected by Excitation Control,” IEEE Trans. PAS, Vol. 88, pp. 316-329, 1969.

[3] T.C. Yang, “Applying H_∞ optimization method to power system stabilizer design parts 1&2.” Int J. Electrical Power Energy Syst. 19 (1), pp 29-43, 1997

[4] P. Kundur, M. Klein, G. J. Rogers, and M. S. Zywno, "Application of Power System Stabilizers for Enhancement of Overall System Stability," IEEE Trans. PWRS, Vol. 4, No. 2, pp. 614-626, 1989.

[5] M. A. Abido and Y. L. Abdel-Magid, “Robust design of multimachine power system stabilizers using tabu search algorithm,” IEE Proceedings-Gener., Transm., Distrib., Vol. 147, No. 6, pp. 387-394, Nov. 2000,

[6] M. A. Abido and Y. L. Abdel-Magid, “Analysis and Design of Power System Stabilizers and FACTS Based Stabilizers Using GA,” Proceedings of PSCC-2002, Session 14 Paper 3, Spain, June 24-28, 2002,

[7]makombe T. and Jenkins N."investigation of a unified power flow controller, generation transmission and distribution" IEE proceeding ,volume 146, no.4,1999,pages(400-408)

[8]limyingcharoen s.,annakkage,u. D.,and pahalawatha N. C.,"effects of power flow unified controller " , generation transmission and distribution, IEE proceeding ,volume 145, no.2,1998,pages(182-188)

[9] fujita, h.,watanabe ,y.,akagi,h.,"control and analysis of a unified power flow controller " power electronics,IEEE transaction on,volume:14 issue:6,nov.1999,pages:1021-1027.

[10] mathur,R. M.,varma r. k., thyristor –based facts controllers for electrical transmission systems ,IEEE press,2002.

[11] wang h. f. ," application of modeling UPFC into multi-machine power systems" generation transmission and distribution ,IEE proceedings ,volume 146 ,no. 3,1999.

[12] Y. Y. Hsu and C. L. Chen, "Identification of optimum location for stabilizer applications using participation factors," IEE Proc., Pt. C, Vol. 134, No. 3, pp. 238-244, May 1987.

[13] Aaron f. snyder " inter-area oscillation damping with power system stabilizers and synchronized phasor measurements" master thesis, Virginia polytechnic institute ,1997.

[14] J. Kennedy, " The Particles Swarm: Social Adaptation of Knowledge," Proceedings of the 1997 IEEE international Conference on Evolutionary Computation ICE'97, Indianpolis, Indiana, USA, pp. 303-308, 1997.

[15] Jaco F. Schutte "The Particle Swarm optimization Algorithm " EGM 6365 - Structural optimization, 2005.