COORDINATED DESIGN OF THYRISTOR CONTROLLED SERIES CAPACITOR AND POWER SYSTEM STABILIZER CONTROLLERS USING VELOCITY UPDATE RELAXATION PARTICLE SWARM OPTIMIZATION FOR TWO-MACHINE POWER SYSTEM STABILITY

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Key words: Thyristor controlled series capacitor (TCSC), Power system stabilizer (PSS), Velocity update relaxation particle swarm optimization (VURPSO).

The thyristor controlled series capacitor (TCSC) and power system stabilizer (PSS) can combine with each other for further damping and stability; therefore, their coordination is very important. In this paper, we use TCSC and PSS simultaneous controllers to increase the stability and damping of the oscillations of the two-machine power system. Then we will optimize the parameters of TCSC and PSS simultaneous controllers by velocity update relaxation particle swarm optimization (VURPSO) algorithm to improve the efficiency of the controllers designed for stability and damping of the oscillations in the power system. VURPSO algorithm complements particle swarm optimization (PSO) algorithm.

1. INTRODUCTION

The power system stabilizer is a device which improves the dynamic operation of the power system by adding the ancillary signals to the stimulation system. This stabilizer is usually fed with the signals like the shaft speed, frequency and power of the generator base and it positively affects the dynamic operation of the power system by damping its oscillations. The main role of PSS is damping the oscillations in the rotor of the generator by controlling its stimulation by application of the ancillary stabilizer signals [1, 2]. Flexible alternating current transmission system (FACTS) devices can control the load distribution and eliminate density and increase the stability level of the network voltage by the capability of making changes in the reactance of the transmission lines. The concept of FACTS devices infers making the transmission system capable by

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activating its elements and parts. TCSC is one of the FACTS devices which can regulate quickly the line impedance and therefore improve the system stability. TCSC is put on the line in a series way to decrease the line impedance. This decrease of impedance, increase the transmission power of the line and therefore, improve the system stability [3, 4]. PSO algorithm is a situation of the algorithm-based social intelligence and is a solution for the optimization problem in a searching area or modeling of the social behavior when the goals exist [5, 6]. PSO optimization algorithm is a social searching algorithm which is modeled based on the social behavior of the birds or fishes groups. Application of PSO optimization algorithm in TCSC is described in [7, 8] and its application in PSS is explained in [9, 10]. VURPSO algorithm complements PSO algorithm. This supplementary method needs less calculation than PSO algorithm and finds the optimized response sooner [11, 12]. In the previous articles, application of the genetic algorithm (GA), ant colony optimization (ACO) and the adaptive neuro-fuzzy inference system (ANFIS), in TCSC were described respectively in [13, 14] and in addition, application of the GA and the ANFIS in PSS were described respectively in [15, 16]. Also, TCSC and PSS simultaneous controllers in [17] and application of the GA in TCSC and PSS simultaneous controllers were described in [18].

In this paper, VURPSO algorithm is used to optimize TCSC and PSS simultaneous controllers' parameters. No need to the dynamics of the studied power system, considering all non-linear features of the system and number of the low iterations for finding the optimized response are among the main features of this method.

2. VURPSO OPTIMIZATION ALGORITHM

VURPSO algorithm complements PSO algorithm. This supplementary method needs less calculation than PSO algorithm and finds the optimized response sooner.

A. Review of PSO algorithm

PSO algorithm is a social searching algorithm which has been modeled based on the social behavior of the birds groups. In fact, each particle is aware of informed about its superiority or lack of superiority over the adjacent particles and also the particles of the whole group. The Equ. (1) of the velocity updating is as following:

$$v_i^{k+1} = v_i^k + c_1 r_1 (pbest_i - s_i^k) + c_2 r_2 (gbest - s_i^k) . \quad (1)$$

And position updating eq. (2) is as following:

$$s_i^{k+1} = s_i^k + v_i^{k+1} , \quad (2)$$

where v_i^k is current velocity of agent *i* at iteration *k* and v_i^{k+1} is modified velocity of agent *i*. s_i^k is current position of agent *i* at iteration *k* and s_i^{k+1} is modified position of agent *i*. $pbset_i$ stands for the best position of the particle *i* and *gbest* represents the best position which the particles have gotten in during implementation of the algorithm. c_1 representing the parameter of individual recognition makes the particle move to the best point that it and its adjacent particles have reached. This coefficient is used as the stimulation coefficient. c_2 representing the social recognition parameter is also used as the stimulation coefficient and it causes the particle to move to the best point the particles have reached yet. r_1 and r_2 are the random numbers in the interval [0,1].

Although PSO algorithm can find out quickly the area of the optimized response, the speed of its convergence decreases to much extent by reaching this area. To solve this problem, eq. (1) is modified as following

$$v_i^{k+1} = w_i v_i^k + c_1 r_1 (pbest_i - s_i^k) + c_2 r_2 (gbest - s_i^k) . \tag{3}$$

In the eq. (2), w_i is weight function for velocity of agent *i*. To control the values of velocity which is shown in eq. (3), we use the maximum velocity parameter $v_{\max}$. If the velocity exceeds this value, the value of $v_{\max}$ stands for it and also if the velocity decreases to a level less than the value of $v_{\min}$, we present $v_{\min}$ as the velocity. Therefore we have: $v_{\min} \le v_i^{k+1} \le v_{\max}$.

Use of inertia weight parameter (w) causes a compromise between the general and local discovery of the group. The big inertia weight is stimulation for discovery in the whole area (movement to the parts of searching area which haven't been already experienced), while a lower weight is a stimulation for discovery in the local areas. The lower weight really makes searching in the already experienced areas continue more carefully. Selection of the appropriate value for w requires making an appropriate balance between the ability of local and general discovery and therefore, it increases the efficiency of the algorithm. The experimental conclusions show that selection of big values for w in the beginning of searching, gives the higher priority to the general discoveries than the local discoveries and with gradual decrease in the value of w, searching in the local areas will be accomplished more seriously [19]. The weight makes the balance between the local and general searching in the algorithm. The appropriate selection of w causes the algorithm to be iteration less to reach the optimized point. In the normal PSO algorithms, w coefficient decreases from 0.9 to 0.4 during implementation of the algorithm and based on:

$$w_i = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{\text{iter}_{\max}} \right) \times \text{iter}, \tag{4}$$

where iter is w current iteration number and $\text{iter}_{\max}$ is maximum iteration number. The flowchart of PSO algorithm is shown in Fig. 1. As P_{fitness} represents the value of the fitness function for each particle and $pbest_{\text{fitness}}$ stands for the best fitness function among the competence functions of the particles.

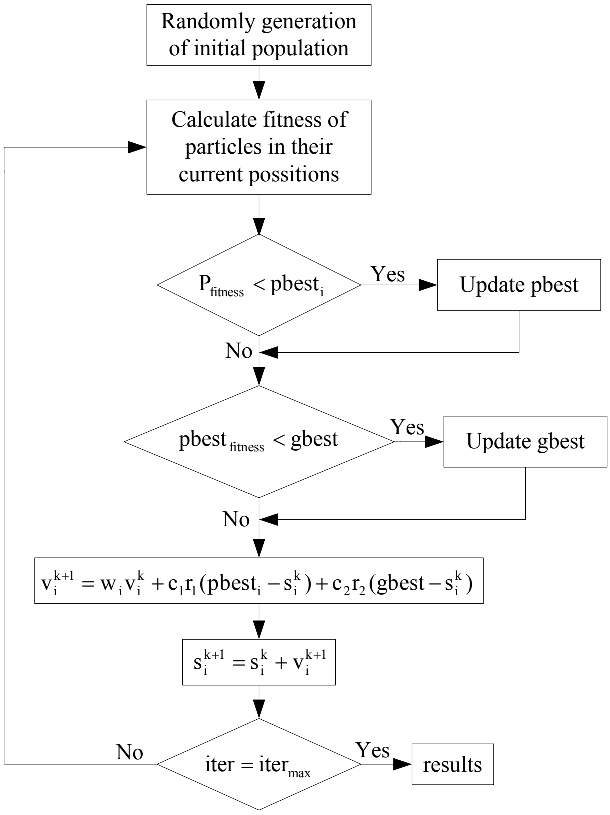

Fig. 1 − Flow chart of the PSO algorithm.

B. Velocity update relaxation PSO

In original PSO algorithm the velocities of the particles are limited in [$v_{\min}$, $v_{\max}$], $v_{\min}$ is usually equal to $s_{\min}$ and $v_{\max}$ equal to $s_{\max}$. The positions of the particles are limited to [$s_{\min}$, $s_{\max}$]. Thus, in traditional PSO, checking about the validity of the position of the particles and then taking some effective position restriction measure to confine or reject solutions accordingly are handled judiciously at every iteration cycle, imposing some extra computational burden. Velocity update relaxation PSO postulates the boundary velocity validity checking of particles without checking the validity of positions in every iteration cycle. Instead velocity-updating relaxation [11] is adopted in every iteration cycle. In traditional PSO algorithm, the velocity is updated at every iteration cycle. According to VUR, keep the velocity of each particle unchanged, if its fitness at current iteration is better than that at preceding iteration; otherwise update the particles' velocity in accordance with (5). This philosophy of velocity updating enhances computational efficiency. Thus, necessary particles' manipulating equations are:

$$v_i^{k+1} = v_i^k + c_1 r_1 (pbest_i - s_i^k) + c_2 r_2 (gbest - s_i^k) \quad (5)$$

In eq. (5), we have: $v_{min}=s_{min}$, $v_{max}=s_{max}$. And position updating Equ. is as following:

$$s_i^{k+1} = (1 - mf)s_i^k + (mf)v_i^{k+1}, \quad (6)$$

where *mf* is momentum factor (0 < *mf* <1). Because 0 < *mf* < 1, the new position vector is the point on the line between the former position vector (s_i^k) and the new velocity vector (v_i^{k+1}). To get good performance, decreasing c_1 and c_2 from 6.5 to 1.5 with iteration cycle and constant *mf* (0.3) are adopted. VURPSO exhibits to have strong global search ability at the beginning of the run and strong local search ability near the end of the run. In this paper, we will optimize TCSC and PSS simultaneous controllers' parameters by use of VURPSO algorithm so that these controllers have a better operation on the power system.

3. POWER SYSTEM MODEL

In this paper, the conditions of the three phase short circuit fault, which is one of the worst conditions for the power system, is studied. The applied power system in this paper includes two synchronous generators of 1000 MVA and of 5000 MVA which are connected by a transmission line of 700 km. The power system model is shown in Fig. 2, where PSS is fixed on the generator and TCSC is put between the bus B_1 and bus B_2. TCSC parameters capacitance: inductor and average firing delay are 20e-6 F, 0.08 H and 4e-3 s. The transformer parameters are:

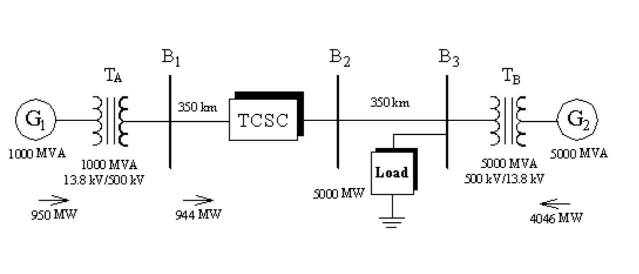

Fig. 2 − Two-machine power system with TCSC.

T_A, T_B: R_1= 0.002 pu, R_2= 0.002 pu, L_1= 0, L_2=0.12, X_m= 500 pu, where R_1 and R_2 are the equivalent resistance, L_1 and L_2 are the equivalent inductance, and X_m is the magnetizing reactance.

4. SIMULATION RESULTS

A number of the values for the parameters of VURPSO optimization algorithm is shown in Table 1. The values for optimized parameters of TCSC and PSS simultaneous controllers with VURPSO algorithm are shown in Table 2. The convergence of the objective function for *gbest* for 100 iterations and 100 particles are shown in Fig. 3. As it can be seen in Fig. 3, the objective function is convergent at the value of 0.019 for *gbest*. In this paper, the most dangerous type of fault, i.e. the three phase short circuit fault with the ground, is studied. It is assumed that in Fig. 2, this fault has been occurred in bus B_1 in 1.1 s and after 100 ms, it is disappeared in 1.2 s. The response of the system in the states with use of TCSC and PSS simultaneous controllers and also with use of VURPSO optimization algorithm is shown in Figs. 4 to 14. The angle of the rotor of generator 1 is unstable because of occurrence the three phase short circuit fault with the ground, but it is damped in about 6 s by use of TCSC and PSS simultaneous controllers and the duration of damping reaches less than 4.5 s and the angle oscillations step down by VURPSO optimization algorithm after occurrence of the fault.

Table 1

The values for VURPSO parameters

Parameters	Values
Number of particles	100
Number of iteration	100
$C_{1,max}$	2.05
$C_{2,max}$	2.05
mf	0.3

Table 2

Values for the optimized parameters of TCSC and PSS simultaneous controllers with VURPSO algorithm

Parameters		Values	Range
TCSC gain	K[pu]	22.8094	1-50
Time constant for TCSC	T_1[s]	0.1322	0.01-1
	T_2[s]	0.1089	0.01-1
	T_3[s]	0.5	0.01-1
	T_4[s]	0.5001	0.01-1
PSS gain and time constant for PSS in area 1	K_{PSSG1}[pu]	30.0017	20-60
	T_{1PSSG1} [s]	0.4812	0.01-1
	T_{1PSSG2} [s]	0.0494	0.01-1
PSS gain and time constant for PSS in area 2	K_{PSSG2}[pu]	29.8135	20-60
	T_{1PSSG2} [s]	0.5	0.01-1
	$T_{2PSSG}2$ [s]	0.5	0.01-1

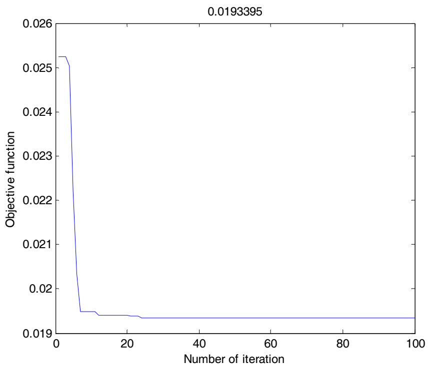

Fig. 3 – Objective function (*gbest*).

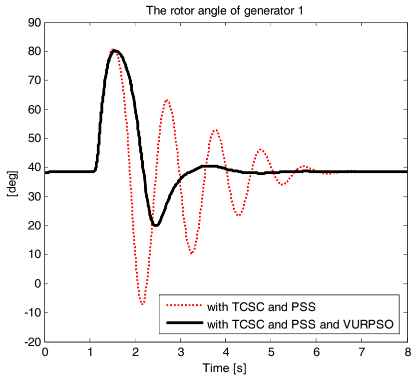

Fig. 4 – Angle of rotor of generator 1.

In Figs. 5 and 6, the speeds of generators 1 and 2 are shown respectively. The speed of generator 1 is unstable because of occurrence of fault but the stability and damping of the speed improves by use of TCSC and PSS synchronous controllers and the speed is damped at the value of 1 p.u in about 4.5 s by VURPSO algorithm. As, it can be seen in Fig. 6, the speed of generator 2 is damped at value of 1 p.u in about 5 s by VURPSO algorithm. The speed deviation of generators 1 and 2 are shown in Figs. 7 and 8. Regarding Fig. 7, the speed deviation of generator 1 is damped in about 5 s by VURPSO algorithm.

Regarding Fig. 8, the speed deviation of generator 2 becomes unstable after the occurrence of faults, but they become damped in about 5 s by use of TCSC and PSS simultaneous controllers and VURPSO optimization algorithm. In Figs. 9 and 10, the terminal voltages of generators 1 and 2 are shown. As it can be seen in Fig. 9, the terminal voltage of the generator 1 become unstable because of the occurrence of faults, but it becomes damped in 4.5 s at 1 p.u by use of TCSC and PSS simultaneous controllers and VURPSO optimization algorithm. Regarding Fig. 10, the terminal voltage of generator 2 is damped in about 5 s at 1 p.u by VURPSO algorithm. The transmission power of the line is shown in Fig. 11.

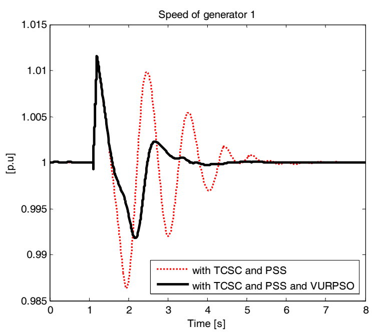

Fig. 5 – The speed of generator 1.

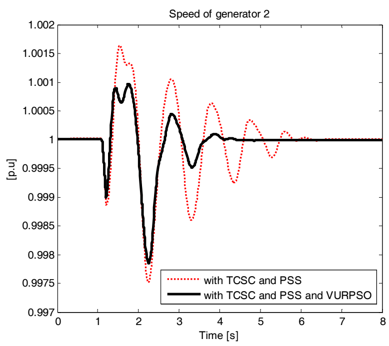

Fig. 6 – The speed of generator 2.

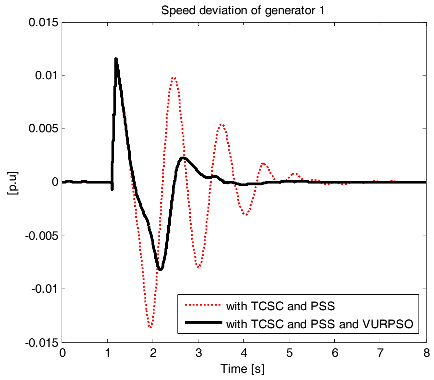

Fig. 7 – The speed deviation of generator 1.

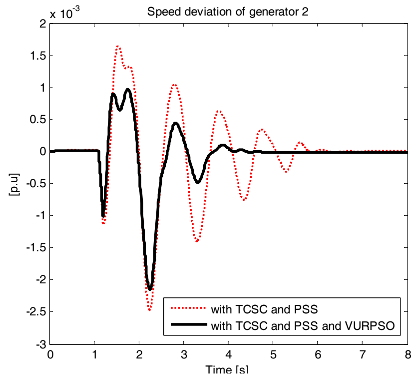

Fig. 8 – The speed deviation of generator 2.

The transmission power of the line shown in Fig. 11 is damped in about 4.5 s at 944 MW by VURPSO algorithm. The voltages of buses B_1, B_2 and B_3 are shown in Figs. 12 and 14. Since the three phase short circuit fault with the ground occurres in bus 1, its voltage changes more at the fault instance than two other buses. In addition, the system oscillations are damped in 4.5 s at 1 p.u by the designed controllers and VURPSO optimization algorithm. As it is shown in Fig. 13, the voltage of bus B_2 is damped in about 4.2 s at 1 p.u by TCSC and PSS simultaneous controllers and VURPSO algorithm. As it can be seen in Fig. 14, the domain of oscillations of the voltage of bus B_3 after the fault occurrence is less than the voltages of buses B_1 and B_2 and it is damped in 4.5 s at 1 p.u by use of TCSC and PSS simultaneous controllers and VURPSO algorithm. As it can be seen in Figs. 4 to 14, the system will be unstable after the three phase short circuit fault with the ground, but the system stability improves by use of TCSC and PSS simultaneous controllers and the oscillations in the system become damped and the stability of the system improves very much and the system become damped more quickly by use of TCSC and PSS simultaneous controllers and VURPSO optimization algorithm. These results show the optimum operation of the designed controllers as well as VURPSO optimization algorithm.

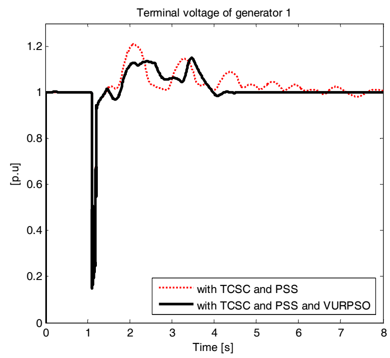

Fig. 9 – The terminal voltage of generator 1.

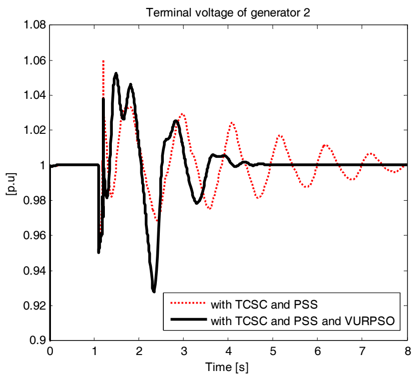

Fig. 10 – The terminal voltage of generator 2.

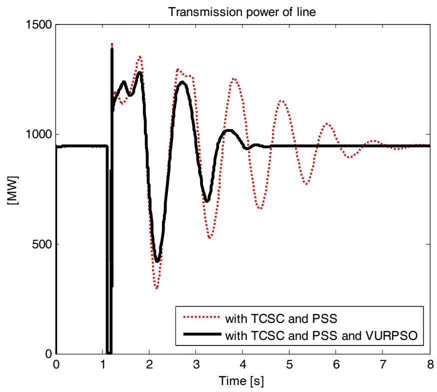

Fig. 11 – The transmission power of line.

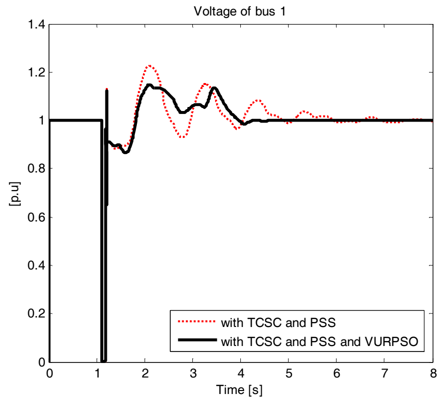

Fig. 12 – The voltage of bus B_1.

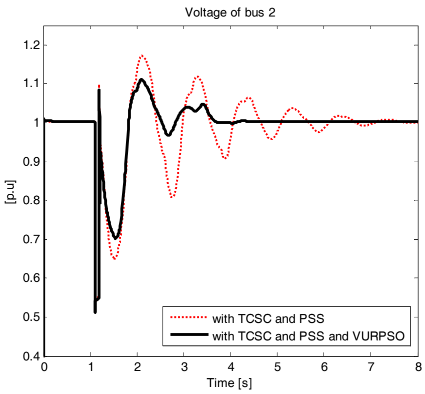

Fig. 13 – The voltage of bus B_2.

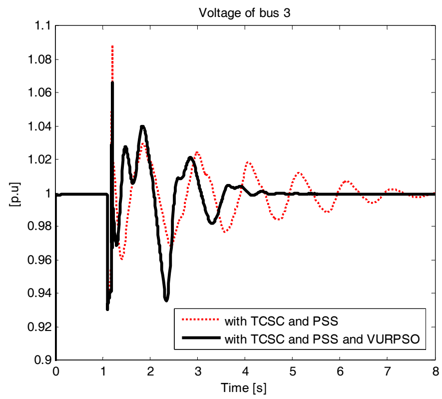

Fig. 14 – The voltage of bus B_3.

5. CONCLUSION

To damp the oscillation and increase the stability of power system, PSS is put in the power plant and FACTS devices are put in the transfer line. Although the lack of coordination between these two stabilizers can result instability in the system. So many studies have been done for coordinated design of PSS and TCSC controllers. In this paper, TCSC and PSS simultaneous controllers were applied and tested in the two-machine non-linear system. The results of simulation show that stability and damping of the system after occurrence of the three phase short circuit fault with the ground improves more by TCSC and PSS simultaneous controllers. Then, the parameters of TCSC and PSS simultaneous controllers were optimized by use of VURPSO optimization algorithm by which stability and damping of the system Increase remarkably.

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REFERENCES

1. U.P. Mhaskar, A.M. Kulkarni, *Power oscillation damping using FACTS devices: Modal controllability, observability in local signals, and location of transfer function zeros*, IEEE Trans. on Pow. Sys., **21**, *2*, pp.285–294, 2006.
2. M.O. Hassan, S.J. Cheng, Z.A. Zakaria, *Optimization of conventional power system stabilizer to improve dynamic stability*, IEEE/ICIEA, Taichung, June 2010, pp. 599–604.
3. D. Floricau, D. Olaru, E. Floricau, I. Popa, *Loss balancing in three-level active-neural-point-clamped conveter*, Rev. Roum. Sci. Techn. – Électrotechn. et Energ., **54**, *3*, pp. 281–290, 2009.
4. S. Shojaeian, J. Soltani, *Low frequency oscillations damping of power system including unified power flow controller based on adaptive backstepping control*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **58**, *2*, pp. 193–204, 2013.
5. Y. Del Valle, G.K. Venayagamoorthy, S. Mohagheghi, J.C. Hernandez, R.G. Harley, *Particle swarm optimization: basic concepts, variants and applications in power systems*, IEEE Trans. on Evol. Com., **12**, *2*, pp.171–195, 2008.
6. D. Schor, W. Kinsner, *A study of particle swarm optimization for cognitive machines*, IEEE/ICCI, 2010, pp. 26–33.
7. S.K. Joshi, K.S. Pandya, *Optimal placement of TCSC for total transfer capability enhancement using particle swarm optimization*, IEEE/APSCOM, Hong Kong, China, 2009, pp.1–6.
8. S. Ray, G. K. Venayagamoorthy, B. Chaudhuri, R. Majumder, *MISO damping controller design for a TCSC using particle swarm*, IEEE/IREP, Charleston, SC, 2007, pp.1–7.
9. T. K. Das, G. K. Venayagamoorthy, *Optimal deign of power system stabilizers using a small population based PSO*, IEEE/PES, Montreal, Que., 2006, pp.17.
10. M.A.Abido, *Optimal design of power system stabilizers using particle swarm optimization*, IEEE Trans. on Ene. Con., **17**, *3*, pp.406–413, 2002.
11. V. Mukherjee, S.P. Ghoshal, *Velocity relaxed swarm intelligent tuning of fuzzy based power system stabilizer*, IEEE/POWERI, New Delhi, June 2006.
12. V. Mukherjee, S.P. Ghoshal, *Craziness based and velocity relaxed swarm optimized intelligent PID controlled AVR system*, IEEE/POWERCON, Oct. 2008, pp.1–8.
13. S. Sreejith, K. Chandrasekaran, S.P. Simon, *Application of touring antcolony optimization technique for optimal power flow incorporating thyristor controlled series compensator*, IEEE/TENCON, Singapore, Jan. 2009, pp. 1–6.
14. S.R. Khuntia, S. Panda, *ANFIS approach for TCSC-based controller design for power system stability improvement*, IEEE/ICCCCT, pp.149–154, Oct. 2010.
15. Y. L. Abdel-Magid, M. A. Abido, *Optimal multi objective design of robust power system stabilizers using genetic algorithms*, IEEE Trans. on Pow. Sys., 18, *3*, pp.1125–1132, 2003.
16. A. Gholipour, H. Lesani, M.K. Zadeh, *Performance of a ANFIS based PSS with tie line active power deviation feedback*, IEEE/PEITS, 2, Shenzhen, Dec. 2009, pp. 267–273.

17. H. Shayeghi, A. Safari, H.A. Shayanfar, *PSS and TCSC damping controller coordinated design using PSO in multi-machine power system*, Eng. Con. and Man., **51**, *12*, pp. 2930–2937, 2010.
18. S. Shajari, M.R. Norouzi, A. Abedini, K. Ahi, *Coordinate control of TCSC based GA controller with PSS for stability improving in single machine system*, IEEE/EEEIC, Rome, May 2011, pp. 1–4.
19. E. Konstantinos, N. Parsopoulos, M. Vrahatis, *On the computation of all global minimizers through particle swarm optimization*, IEEE Trans. on Evol. Comp., **8**, *3*, 2004.