International Journal on "Technical and Physical Problems of Engineering" (IJTPE)
Published by International Organization of IOTPE
ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com
March 2013 Issue 14 Volume 5 Number 1 Pages 44-51

STATIC VAR COMPENSATOR CONTROLLER DESIGN FOR IMPROVING POWER SYSTEM STABILITY

S. Jalilzadeh M. Darabian M. Azari

Electrical Engineering Department, University of Zanjan, Zanjan, Iran
jalilzadeh@znu.ac.ir, m.darabian@znu.ac.ir, m.azari@znu.ac.ir

Abstract- This is the purpose of this paper to design of multi-machine Static VAR Compensator (SVC) using Imperialist Competitive Algorithm (ICA). The SVC parameters designing problem is converted to an optimization problem in which the Integral of Time multiply Absolute Error (*ITAE*) of the speed deviations of machines used as the fitness function. The effectiveness of the proposed approach is confirmed on multi-machine power systems over a wide range of loading conditions. The results of tuned SVC controller based on ICA (ICASVC) is compared with particle swarm optimization based SVC (PSOSVC) through some performance to demonstrate its strong efficiency. The superiority of the proposed tuned controller is verified by giving better damping performance.

Keywords: Imperialist Competitive Algorithm (ICA), Particle Swarm Optimization (PSO), SVC Design, Transient Stability.

I. INTRODUCTION

The transient stability issue has been challenging researchers of the electrical power field for many years. The transient stability plays the main role in determining the capacity of power transfer, planning and scheduling power systems. With rapid growth of power systems in recent decades, some of areas of a large scale power system may be interconnected by weak tie-lines. So the low frequency oscillations (LFO) can be observed. If these oscillations are not restrained, the instability will occur certainly in the power systems. Accordingly, preventive measures should be performed to overcome this problem. In this regard, researchers' effort has led to many controllers so far. One of the effective methods for improving the transient stability is to use flexible AC transmission system (FACTS) devices. FACTS devices can approximately be used for any purpose in power systems [1-5]. The most popular type of FACTS devices in terms of application is the SVC. SVC is usable for power oscillation damping, improvement stability and frequency stabilization [6]. By changing its reactance characteristic from inductive to capacitive, the SVC can control the power flow and enhance the capability of power transfer in power systems.

Also, an auxiliary controller can be added to the SVC for improving the transient stability [7]. In recent years, numerous schemes have been documented for SVC parameters optimization so as to improve the damping of power system oscillations. In [8], an adaptive network based fuzzy inference system (ANFIS) is represented to improve power system damping via SVC. In [9], a new scheme is proposed to find optimal location of SVCs to increase power system stability. In order to increase power system stability, a new scheme based on wide area signals via SVC is suggested in [10]. A BFOA algorithm is represented in [11] to design SVC parameters in a single machine infinite bus system. In [12], a pade approximation technique is suggested to design of SVC with delayed input signal. In [13], a new hybrid scheme is addressed to simulate power systems equipped with SVC. A simultaneous tuning of a PSS and a SVC controller based on Genetic Algorithm (GA) is proposed in [14]. The adjusted design of PSSs and SVC based on probabilistic theory is described in [15]. In [16], the decentralized modal control technique is applied to pole placement in multi-machine power system using FACTS devices. In [17], an extensive evaluation is performed on PSS and FACT device when applied independently as well as in a coordinated mode.

The major contribution of this paper is designing the SVC damping controller so as to enhance the power system stability using imperilalist competitive algorithm (ICA). The SVC parameters designing problem is converted to an optimization problem in which the speed deviations between generators are involved. The effectiveness of the proposed approach is confirmed on multi-machine power systems under different operating conditions and disturbances. The results of tuned SVC controller based on ICA (ICASVC) is compared with the particle swarm optimization based SVC (PSOSVC) uder different condition and disturbance to indicates its strong performance.

This paper is set out as follows: Problem statement is formulated in Section II. Heuristic optimization methods for solving the problem are presented in Section III. The application of the proposed model and simulation results are presented in Section IV and finally, the conclusion is presented in Section V.

II. PROBLEM STATEMENT

A. Power System Model

A power system can be stated by a set of nonlinear differential equations as follow:

$$\dot{X} = f(X,U) \tag{1}$$

The linearized incremental models around an equilibrium point are usually employed in the design of PSS and SVC. Hence, the state equation of a power system with n machines and m PSS and SVC can be formulated as follow:

$$\dot{X} = AX + BU \tag{2}$$

Definitions of symbols are as follows: X is the vector of the state variables; U is the vector of input variables; in this paper $X = [\delta, \omega, E_q', E_{fd}, V_f]^T$ and U is the PSS and SVC output signals; δ and ω are the rotor angle and speed, respectively; E_q', E_{fd} and V_f are the internal, the field, and excitation voltages respectively; A is a $5n\times5n$ matrix and equals $\partial f/\partial X$; B is a $5n\times m$ matrix and equals $\partial f/\partial U$; X is a $5n\times1$ state vector; U is an $m\times1$ input vector.

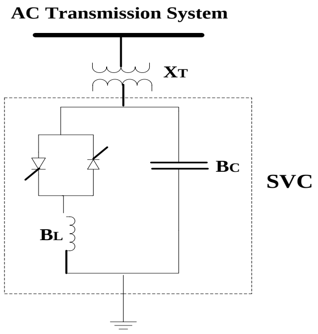

Figure 1. SVC equivalent circuit

B. SVC Structure

The SVC model used in this study is depicted in Figure1. Then, this system is connected to the AC system via a transformer to bring the voltages up to the required transmission levels. As seen from (3) and Figure 2, by controlling the firing angle α of the thyristors; the bus voltage magnitude can be controlled by SVC. Time constant (T_r) and gain (K_r) demonstrate the thyristors firing control system.

$$\dot{B}_e = \frac{1}{T_r}[-B_e + K_r(V_{ref} - V_t + V_s)] \tag{3}$$

The variable effective susceptance of this model as Figure 2 is stated in Equation (4).

$$B_V = -\frac{2\pi - 2\alpha + \sin 2\alpha}{\pi X_L} \quad , \quad \pi/2 \le \alpha \le \pi \tag{4}$$

where X_L is the reactance of the fixed inductor of SVC. The efficient reactance is formulated as follow:

$$X_e = X_c \frac{\pi / r_x}{\sin 2\alpha - 2\alpha + \pi(2 - 1/r_x)} \tag{5}$$

where $X_e = -1/B_e$ and $r_x = X_e/X_L$. The Figure 2 illustrates the block diagram of a SVC with auxiliary stabilizing signal. This controller, which is assumed as a lead lag compensator, includes gain block two stages of lead lag compensator and signal washout block.

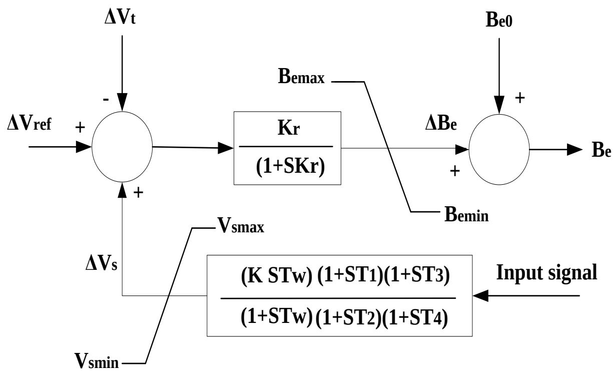

Figure 2. Block diagram of SVC

C. System under Study

The single line diagram of the test system used in this paper is depicted in Figure 3. The system data is represented in [18]. The eigenvalues and frequencies connected to the rotor oscillation modes of the system are tabulated in Table 1. As it can be seen from the table, the 0.2371 Hz mode is the interarea mode with G_1 oscillating against G_2 and G_3.

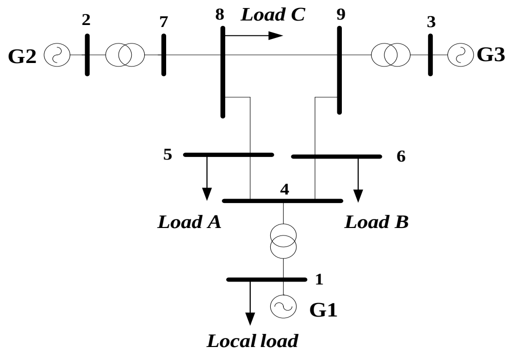

Figure 3. System under study

The 1.2955 and 1.8493 Hz modes are the intermachine oscillation local to G_2 and G_3, respectively. Furthermore, the instability of the system is revealed by the positive real part of proper value of G_1. Table 2 shows the system and generator loading levels. Two master plans will be demonstrated below so as to find the appropriate place of the SVC in the system. The first strategy is based on investigating the impact of load percentage and the second on is involved with system voltages owing to the line outage [19]. The effect of load percentage and line outage on bus voltages of the system are given in Tables 3 and 4. It can be observed that the voltages are influenced remarkably at load buses numbered 5 and 6, respectively. This fact can be arisen from the connection of these buses with the longest lines in the system which possesses bigger resistances and reactances than the others. As a result the buses number 5 or 6 can be assumed as the best candidate for the SVC placing. Both candidates are adjacent machine number 1 which brings about the system instability owing to its unstable mechanical mode. Additionally, bus number 5 is the worst one and will be assumed as the best candidate to install the SVC.

Table 1. The eigenvalues and frequencies connected to the rotor oscillation mode of the system

Generator	Eigenvalues	Frequencies	Damping ratio ζ
G_1	+0.15 ± 1.49j	0.2371	-0.1002
G_2	-0.35 ± 8.14j	1.2955	0.0430
G_3	-0.67 ± 11.62j	1.8493	0.0576

Table 2. Loading condition for the system

Gen.	Light		Normal		Heavy	
	P	*Q*	*P*	*Q*	*P*	*Q*
G_1	0.9649	0.223	1.7164	0.6205	3.5730	1.8143
G_2	1.0000	-0.1933	1.630	0.0665	2.20	0.7127
G_3	0.4500	-0.2668	0.85	0.1086	1.35	0.4313
Load						
A	0.70	0.350	1.25	0.5	2.00	0.90
B	0.50	0.30	0.9	0.30	1.80	0.60
C	0.600	0.200	1.00	0.35	1.60	0.65
Local load	0.600	0.200	1.000	0.35	1.60	0.65

Table 3. Effect of load percentage on load bus voltage

Load%	0.25	0.5	0.75	1.00	1.25	1.5	1.75
Bus 4	1.0573	1.0479	1.0375	1.0258	1.0126	0.9975	0.9799
Bus 5	1.0593	1.0403	1.0192	0.9956	0.9691	0.9389	0.9036
Bus 6	1.0643	1.0487	1.0315	1.0127	0.9917	0.9681	0.9036
Bus 7	1.0500	1.0434	1.0354	1.0258	1.0143	1.0005	0.9839
Bus 8	1.0535	1.0425	1.0300	1.0159	0.9998	0.9814	0.9599
Bus 9	1.0508	1.0456	1.0395	1.0324	1.0241	1.0144	1.0029

Table 4. Effect of line outage on load bus voltage

Line Outage	4-5	4-6	5-7	6-9	7-8	8-9
Bus 4	1.0388	1.0282	0.9956	1.0189	1.0234	0.9994
Bus 5	0.8389	0.9988	0.9380	0.9678	0.9736	0.9897
Bus 6	1.0203	0.9418	0.9748	0.9678	0.9994	0.9897
Bus 7	0.9878	1.0223	1.0170	1.0156	0.9994	1.0100
Bus 8	0.9895	1.0063	1.0010	1.0054	0.9994	1.0100
Bus 9	1.0244	1.0167	1.0189	1.0234	0.9994	1.0100

D. Objective Function

The main aim here is to coordinated design of SVC via ICA technique. The advantage of this selected performance index is that minimal dynamic plant information is needed optimization is used to seek the optimum controller parameters so as to improve the system damping properties. For this purpose, the design problem can be formulated with the following fitness function which is based on the Integral of Time Multiple Absolute Error (*ITAE*) as follow:

$$J = \int_0^\infty t(|\Delta\omega_{12}| + |\Delta\omega_{23}| + |\Delta\omega_{13}|)dt \tag{6}$$

where $\Delta\omega_{ij} = \Delta\omega_i - \Delta\omega_j$. The major goal is to minimize the *J*, as follow:

$$OF : \text{minimize}(J) \tag{7}$$

The limitation of the parameters is tabulated in Table 5. Enhancing the damping properties as well as acquiring a good performance through different operating conditions is the main contribution of optimization process.

Table 5. SVC boundaries

Generator	T_1	T_3	*K*
Minimum	0.06	0.06	1
Maximum	1.0	1.0	100

III. HEURISTIC OPTIMIZATION METHOD

A. Imperialist Competitive Algorithm

The ICA was first proposed in [20]. It is inspired by the imperialistic competition. It starts with an initial population called colonies. The colonies are then categorized into two groups, namely, imperialists (best solutions) and colonies (rest of the solutions). The imperialists try to absorb more colonies to their empire [21-23]. The colonies will change according to the policies of imperialists. The colonies may take the place of their imperialist if they become stronger than it (propose a better solution). The flowchart of the proposed algorithm is shown in Figure 4. The steps of the proposed ICA are described as follows:

Step 1. Generate an initial set of colonies with a size of N_c.

Step 2. Set iteration = 1.

Step 3. Calculate the objective function for each colony and set the power of each colony as follows:

$$CP_c = OF \tag{8}$$

Step 4. Keep the best N_{imp} colonies as the imperialists and set the power of each imperialist as follows:

$$IP_i = OF \tag{9}$$

Step 5. Assign the colonies to each imperialist according to the calculated IP_i. This means the number of colonies owned by each imperialist $(IP_i / \sum_{j=1}^{N_{imp}} IP_j) \times (N_c - N_{imp})$ is proportional to its power, IP_i.

Step 6. Move the colonies towards their relevant imperialist using crossover and mutation operators.

Step 7. Exchange the position of a colony and the imperialist if it is stronger $CP_c > IP_i$.

Step 8. Compute the empire's power, that is, EP_i for all empires as follows:

$$EP_i = \frac{1}{N_{E_i}}(\chi_1 \times IP_i + \chi_2 \times \sum_{c \in E_i} CP_c) \tag{10}$$

where χ_1 and χ_2 are weighting factors that are adaptively selected.

Step 9. Pick the weakest colony and give it to one of the best empires (select the destination empire probabilistically based on its power, EP_i).

Step 10. Eliminate the empire that has no colony.

Step 11. If more than one empire remained then go to Step 6.

Step12. End.

B. Particle Swarm Optimization

The PSO is a population based stochastic optimization technique developed by Eberhart and Kennedy in 1995 [24, 25]. The PSO algorithm is inspired by social behavior of bird flocking or fish schooling. The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas [13]. The standard PSO algorithm employs a population of particles. The particles fly through the *n*-dimensional domain space of the function to be optimized. The state of each particle is represented by its position $X_i = (X_{i1}, X_{i2}, ..., X_{in})$ and velocity $V_i = (V_{i1}, V_{i2}, ..., V_{in})$ the states of the particles are updated. The three key parameters to PSO are in the velocity update equation (11). First is the momentum component, where the inertial constant w, controls how much the particle remembers its previous velocity [26].

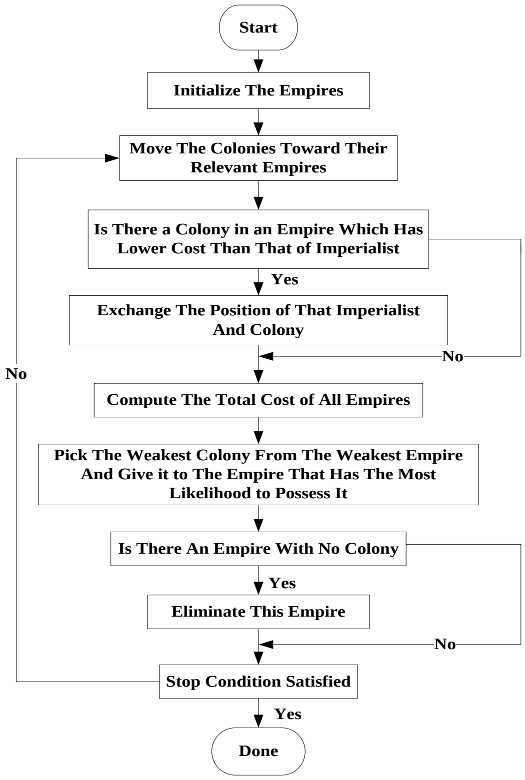

Figure 4. ICA flowchart

The second component is the cognitive component. Here the acceleration constant c_1, controls how much the particle heads toward its personal best position. The third component, referred to as the social component, draws the particle toward swarm's best ever position; the acceleration constant c_2 controls this tendency. The flow chart of the procedure is shown in Figure 5. Each particle is updated by two "best" values during every iteration. The first one is the position vector of the best solution (fitness) this particle has achieved so far.

$$v_i^{k+1} = wv_i^k + c_1 r_1 (pbset_i - x_i^k) + c_2 r_2 (gbset_k - x_i^k) \quad (11)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (12)$$

The fitness value $p_i = (p_{i1}, p_{i2}, ..., p_{in})$ is also stored. This position is called *pbest*. Another "best" position that is tracked by the particle swarm optimizer is the best position, obtained so far, by any particle in the population.

This best position is the current global best $p_g = (p_{g1}, p_{g2}, ..., p_{gn})$ and is called *gbest*. At each time step, after finding the two best values, the particle updates its velocity and position according to (11) and (12).

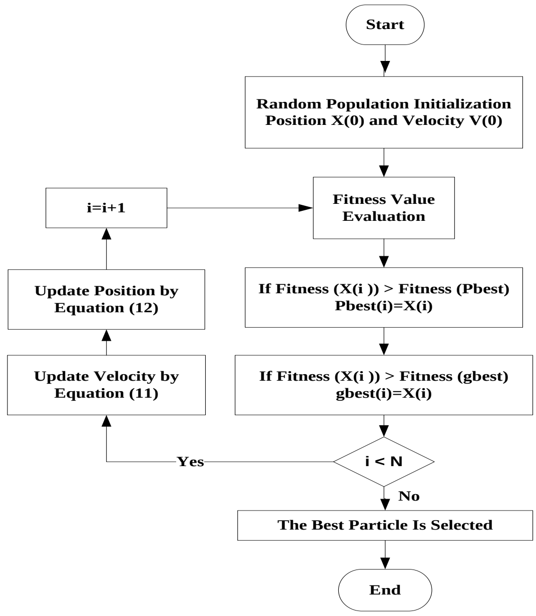

Figure 5. PSO flowchart

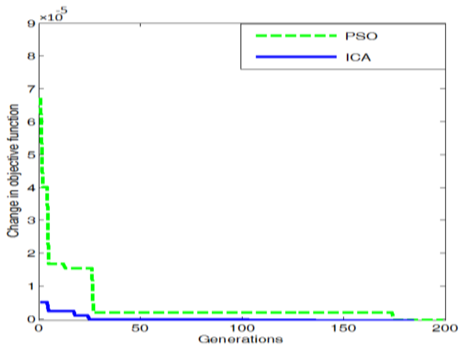

Figure 6. Convergence profile for ICA and PSO

IV. SIMULATION RESULTS

A. Determination of ICA Parameters

Crossover and mutation probabilities used at the above Step 6 affect the final solution of the ICA problem. In this sub-section the effect of these probabilities on the average fitness function is investigated and optimum values are selected for them. To do so, for a colony size of 100 (N_c=100), the crossover and mutation probabilities are increased from 0.1 to 0.9 in steps of 0.1, respectively. Then, for every couple of the crossover and mutation probabilities, 10 independent trials are made with the solution of the ICA problem each with 100 iterations and average fitness function among 10 trials is determined. The optimum values for the two probabilities are those giving minimum average fitness function are selected as: crossover probability = 0.3 and mutation probability = 0.7. The other simulation parameters of ICA and PSO are shown in Table 6.

Table 6. ICA and PSO simulation parameters

Method	Fixed Parameters
ICA	N_{imp}=3; χ_1=0.85; χ_2=0.25; V_{max}=1.05; V_{min}=0.95
PSO	N_c = 200; C_1=2; C_2=2; r_1=1.1; r_2=1.1

B. Comparing Results

The minimum fitness value evaluating process is depicted in Figure 6. As it can be seen from the figure, the convergence of ICA is faster than PSO. This is because ICA algorithm provides the correct answers with high accuracy in the initial iterations which makes the responding time of this algorithm extremely fast. The system eigenvalues and damping ratio of mechanical mode with three different loading conditions is tabulated in Table 7. The instability of open loop system for light, normal, and heavy loading conditions can be easily observed from the table. The ICASVC shifts significantly the electromechanical mode eigenvalues to the left of the S-plane, and consequently the values of the damping factors are considerably improved to (ω = -0.69, -0.81, -0.89) for light, normal, and heavy loading respectively. Table 8 shows optimized parameters values of different controllers based on the time domain objective function through proposed ICA technique.

C. Light Load Condition

The robust efficiency of the proposed ICASVC is confirmed by implementing a three phase fault of 6 cycle duration at 1.0 s near bus 7. The response of $\Delta\omega_{12}$, $\Delta\omega_{23}$ and $\Delta\omega_{13}$ owing to severe disturbance for light loading condition are shown in Figures 7-9. It is clear from these figures that the proposed controller attains better performance and supplies superior damping compared with the other technique. The required mean time to diminish these oscillations (settling time) is nearly 1.96 s and 2.45 sec for ICASVC and PSOSVC, respectively. Therefore, the designed controller is able to achieve adequate damping to the system oscillatory modes. Additionally, the oscillations are grown quickly in the case of open loop system.

Table 7. Mechanical modes and ζ under different loading conditions and controllers

Load	Without SVC	PSOSVC	ICASVC
Light	0.91±9.83j , 0.093	-1.95±8.55j , 0.2241	-2.22±8.25j , 0.2627
	-0.56±7.56 , 0.073	-3.16±8.34j , 0.361	-3.38±7.02j , 0.4484
	+0.05±0.91j , -0.054	-0.41±0.95j, 0.4073	-0.69±0.94j , 0.6329
Normal	-0.61±11.89j , 0.0512	-2.12±10.66j , 0.1962	-2.51±10.02j , 0.2453
	-0.45±8.12j , 0.0554	-1.95±7.21j, 0.2642	-2.31±6.89j , 0.3233
	+0.12±1.65j , -0.02456	-0.45±0.85j , 0.486	-0.81±0.95j , 0.7005
Heavy	-0.43±12.04j , 0.0356	-1.84±11.45j , 0.1593	-2.26±11.11j , 0.2006
	-0.21±8.75j , 0.0234	-1.12±6.88j , 0.1612	-1.28±6.61j ,0.1911
	+0.03±1.69j , -0.017	-0.52±0.96j , 0.4962	-0.88±0.74j , 0.8712

Table 8. Optimal SVC parametes based on ICA and PSO techniques

Parameters	PSOSVC	ICASVC
K	73.6102	46.5211
T_1	0.7601	0.5401
T_3	0.9014	0.4966

D. Normal Load Condition

The response of $\Delta\omega_{12}$, $\Delta\omega_{23}$ and $\Delta\omega_{13}$ owing to same disturbance for normal loading condition are depicted in Figures 10-12. The obtained results reveal that the proposed coordinated controller has a superior ability for damping power system oscillations and intensifies substantially the dynamic stability of the power system. In addition, the mean settling times are T_s = 2.22 and 2.89 sec for ICASVC and PSOSVC, respectively. The instability of open loop system is clear from the figures. As a consequence, the ability of attaining better system oscillation damping via ICASVC is verified by comparing with PSOSVC as well as open loop case.

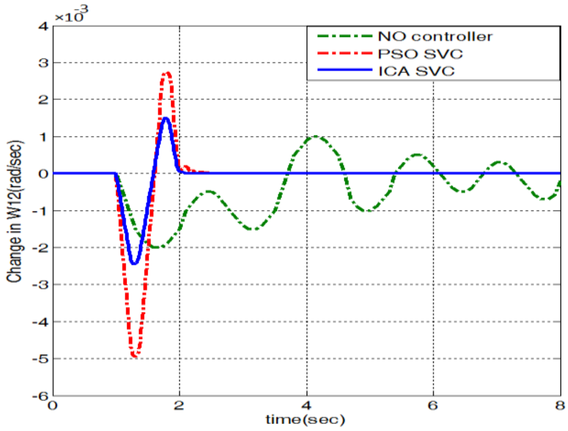

Figure 7. Response of $\Delta\omega_{12}$ for light load condition

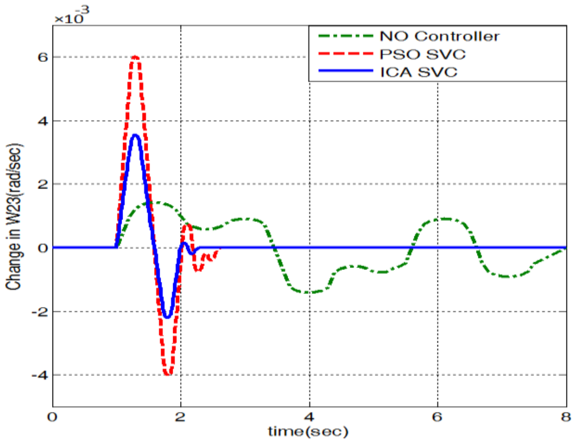

Figure 8. Response of $\Delta\omega_{23}$ for light load condition

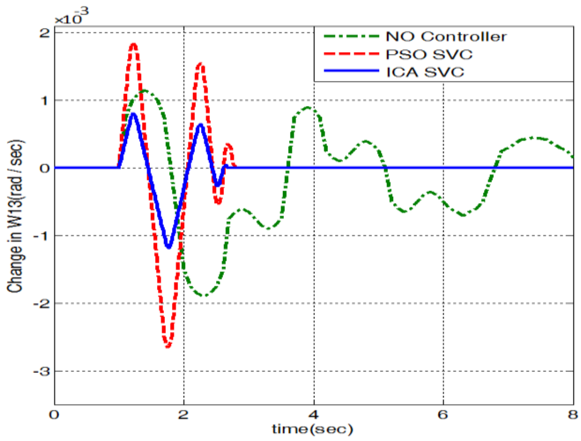

Figure 9. Response of $\Delta\omega_{13}$ for light load condition

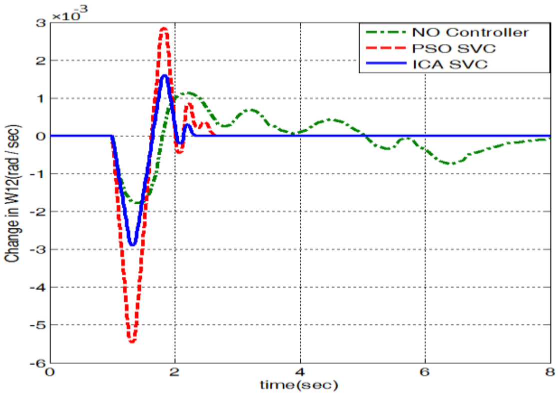

Figure 10. Response of $\Delta\omega_{12}$ for normal load condition

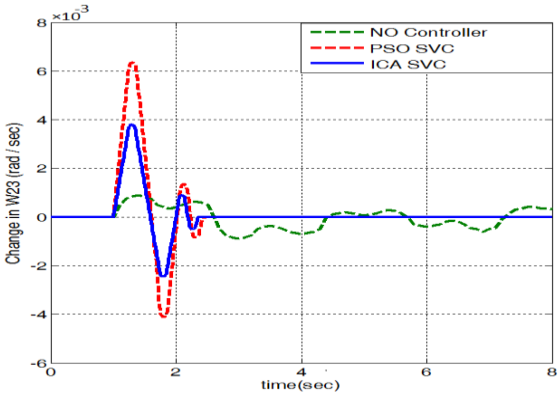

Figure 11. Response of $\Delta\omega_{23}$ for normal load condition

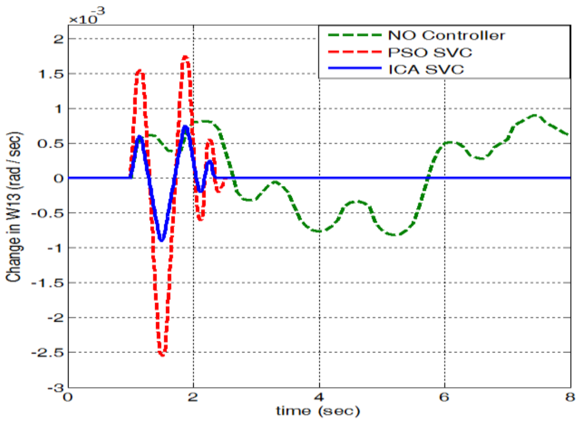

Figure 12. Response of $\Delta\omega_{13}$ for normal load condition

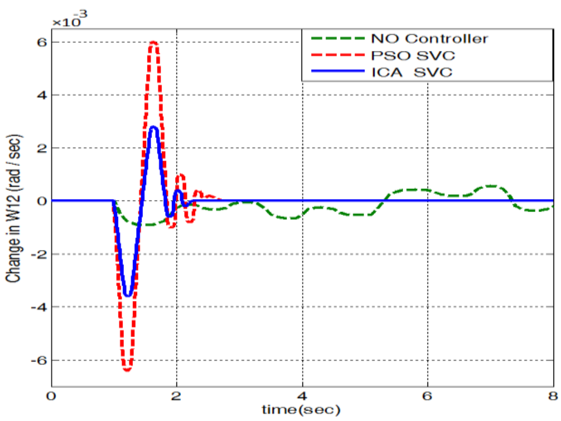

Figure 13. Response of $\Delta\omega_{12}$ for heavy load condition

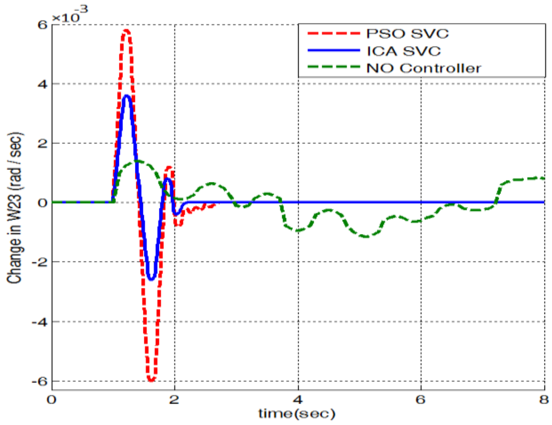

Figure 14. Response of $\Delta\omega_{23}$ for heavy load condition

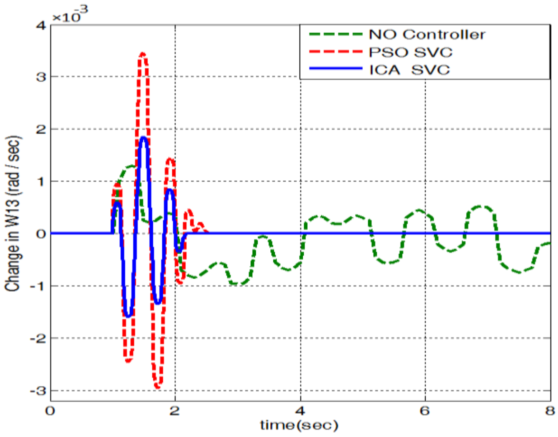

Figure 15. Response of $\Delta\omega_{13}$ for heavy load condition

E. Heavy Load Condition

The response of $\Delta\omega_{12}$, $\Delta\omega_{23}$ and $\Delta\omega_{13}$ for heavy loading condition are illustrated in Figures 13-15. It is obvious from the figures that the proposed ICASVC controller demonstrates better damping properties to low frequency oscillations and faster stability in comparison with PSOSVC. The mean settling time are T_s = 2.28 and 2.81 sec for ICASVC and PSOSVC respectively. Consequently, the power transfer ability as well as the power system stability is increased by way of the proposed ICASVC controller.

V. CONCLUSIONS

This paper addresses a robust design technique for tuning of SVC damping controller in a multi-machine power system. The SVC parameters designing problem is converted to an optimization problem in which the speed deviations between generators are involved and imperialist competitive algorithm (ICA) is utilized to seek optimal parameters. The efficiency of the proposed scheme is confirmed on a multi-machine power system for a wide range of loading conditions and disturbances. The results are compared with PSO based tuned SVC (PSOSVC) to indicate its ability. The proposed ICA scheme for adjusting SVC is easy to implement without additional computational complexity. In addition, the power system stability and also power transfer capability are extended via the proposed scheme.

REFERENCES

[1] M. Pahlavani, H. Mohammadpour, "Damping of Subsynchronous Resonance and Low Frequency Power Oscillation in a Series Compensated Transmission Line Using Gate Controlled Series Capacitor", Electric Power Syst. Res., Vol. 81, No. 2, pp. 308-317, 2011.

[2] K. Padiyar, N. Prabhu, "Design and Performance Evaluation of Subsynchronous Damping Controller with STATCOM", IEEE Trans. on Power Delivery, Vol. 21, No. 3, pp. 1398-1405, 2006.

[3] M. Majdi, Z. Jian Guo, "Bifurcation Control of Subsynchronous Resonance Using TCSC", Commun. Nonlinear Sci. Numer. Simulat, Vol. 16, No. 5, pp. 2363-2370, 2011.

[4] S. Panda, "Multiobjective Evolutionary Algorithm for SSSC Based Controller Design", Electr. Power Syst. Res., Vol. 79, No. 6, pp. 937-944, 2009.

[5] F.C. Jusan, S. Gomes, G. Nery Taranto, "SSR Results Obtained with a Dynamic Phasor Model of SVC Using Modal Analysis", Electr. Power Energy Syst., Vol. 32, No. 6, pp. 571-582, 2010.

[6] D. Rai, S. Faried, G. Ramakrishna, A. Edris, "Hybrid Series Compensation Scheme Capable of Damping Subsynchronous Resonance", IET Gener. Transm. Distrib, Vol. 4, No. 3, pp. 456-466, 2010.

[7] H. Wang, "Static Synchronous Series Compensator to Damp Power System Oscillations", Electr. Power Syst. Res, Vol. 54, No. 2, pp. 113-119, 2000.

[8] M. Furini, A. Pereira, P. Araujo, "Pole Placement by Coordinated Tuning of Power System Stabilizers and FACTS POD Stabilizers", Int. J. Electr. Power Energy Syst., Vol. 33, No. 3, pp. 615-622, 2011.

[9] M. Haque, "Best Location of SVC to Improve First Swing Stability of a Power System", Int. J. Electr. Power Syst. Res, Vol. 77, No. 10, pp. 1402-1409, 2007.

[10] Y. Chang, Z. Xu, "A Novel SVC Supplementary Controller Based on Wide Area Signals", Int. J. Electr. Power Syst., Res., Vol. 77, No. 12, pp. 1569-1574, 2007.

[11] E. Ali, "Static VAR Compensator Design for Power System Stabilization Using Bacteria Foraging Optimization Algorithm", 13th International Middle East Power Systems Conference (MEPCON 2009), Assiut University, Assiut, Egypt, pp. 578-582, Dec. 20-23, 2009.

[12] Y. Yuan, G. Li, L. Cheng, Y. Sun, J. Zhang, P. Wang, "A Phase Compensator for SVC Supplementary Control to Eliminate Time Delay by Wide Area Signal Input", Int. J. Electr. Power Energy Syst., Vol. 32, No. 3, pp. 163-9, 2010.

[13] E. Zhijun, D. Fang, K. Chan, S. Yuan, "Hybrid Simulation of Power Systems with SVC Dynamic Phasor Model", Int. J. Electr. Power Energy Syst., Vol. 31, No. 5, pp. 175-178, 2009.

[14] S. Panda, N. Patidar, R. Singh, "Simultaneous Tuning of SVC and Power System Stabilizer Employing Real Coded Genetic Algorithm", Int. J. Electr. Electron. Eng., Vol.4, No. 4, pp. 240-247, 2009.

[15] X. Bian, C. Tse, J. Zhang, K. Wang, "Coordinated Design of Probabilistic PSS and SVC Damping Controllers", Int. J. Electr. Power Energy Syst., Vol. 33, No. 3, pp. 445-452, 2011.

[16] M. Furini, A. Pereira, P. Araujo, "Pole Placement by Coordinated Tuning of Power System Stabilizers and FACTS POD Stabilizers", Int. J. Electr. Power Energy Syst., Vol. 33, No. 3, pp. 615-622, 2011.

[17] E. Ali, S. Abd Elazim, "Coordinated Design of PSSs and TCSC via Bacterial Swarm Optimization Algorithm in a Multimachine Power System", Int. J. Electr. Power Energy Syst., Vol. 36, No. 1, pp. 84-92, 2012.

[18] P. Anderson, A. Fouad, "Power System Control and Stability", Iowa State University Press, Iowa, USA, 1977.

[19] S. Abd Elazim, "Comparison between SVC and TCSC Compensators on Power System Performance", Master Thesis, Zagazig University, Egypt, 2006.

[20] J. Atashpaz Gargari, E. Lucas, "Imperialist Competitive Algorithm: An Algorithm for Optimization Inspired by Imperialistic Competition", IEEE Cong. on Evolutionary Computation, CEC, pp. 4661-4667, 2007.

[21] S. Jalilzadeh, M. Azari, "A Novel Approach for PID Designing for Load Frequency Control System", International Review on Modeling and Simulation (I.RE.MO.S), Vol. 5, No. 3, pp. 1159-1164, 2012.

[22] E. Bijami, J. Askari Marnani, S. Hosseinnia, "Power System Stabilization Using Model Predictive Control Based on Imperialist Competitive Algorithm", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 9, Vol. 3, No. 4, pp. 45-51, December 2011.

[23] A. Jalilvand, M. Azari, "Robust Tuning of PSS Controller Based on Imperialist Competitive Algorithm", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 13, Vol. 4, No. 4, pp. 5-10, December 2012.

[24] J. Kennedy, R.C. Eberhart, "Particle Swarm Optimization", Int. Conf. on Neural Networks, pp. 1942-1948, Perth, Australia, 1995.

[25] R.C. Eberhart, Y. Shi, "Particle Swarm Optimization: Developments, Applications and Resources", Int. Conf. on Evolutionary Computation, pp. 81-86, Seoul, Korea, 2001.

[26] Y. Shi, R. Eberhart, "A Modified Particle Swarm Optimizer", Int. Conf. on Evolutionary Computation, Anchorage, pp. 69-73, AK, USA, 1998.

BIOGRAPHIES

Saeid Jalizadeh was born in Salmas, Iran, 1962. He received his B.Sc. and M.Sc. degrees both in Electrical Engineering from University of Tabriz, Tabriz, Iran, in 1986 and 1989, respectively. He received Ph.D. degree in Electrical Engineering from Iran University of Science and Technology, Tehran, Iran, in 2005. Currently, he is an Associate Professor at Technical Engineering Department, Zanjan University, Zanjan, Iran. He is author of more than 60 journal and conference papers. His research interests are dynamic stability, power market, and renewable energy in power system, power system contingency analysis and power system planning. He is a member of institute of electrical and electronics engineers (IEEE).

Mohsen Darabian received his B.Sc. degree in Electrical Engineering from Abhar Branch, Islamic Azad University, Abhar, Iran, in 2010. He is currently a M.Sc. student at Department of Power Engineering, University of Zanjan, Zanjan, Iran. His research interests include application of intelligent methods in power systems, distributed generation modeling, power electronic, FACTS, power quality and power system dynamics.

Mehdi Azari was born in Zanjan, Iran, in 1986. He received his B.Sc. degree in Electrical Engineering from University of Zanjan, Zanjan, Iran, in 2008. He is currently a M.Sc. student at Department of Electrical Engineering, University of Zanjan, Zanjan, Iran. His research interests include application of intelligent methods in power systems, distributed generation modeling, power system protection and control and digital protective relays.