example, line active power and current carry such valuable information. Transmission line active power has been proposed as an effective input signal in [12, 13] for series FACTS devices damping controller design. For this reason, here, the active power of the transmission line is selected as the input signal. The power flow in line 5-7 is the largest power flow in the system under study [13]. Moreover, this line is the longest line in the system. So, one will consider this line as the best location for installing the SSSC controller in this paper. Also, the objective function is modified to be

$$J = \int_0^{t_{sim}} t\left\{\left|\Delta\omega_{12} + \Delta\omega_{23} + \Delta\omega_{13}\right| + \left|\Delta V_{DC}\right| + \left|\Delta P_{line57}\right|\right\} dt$$

Table 4, shows the parameters of SSSC controller obtained by various algorithms for multimachine system.

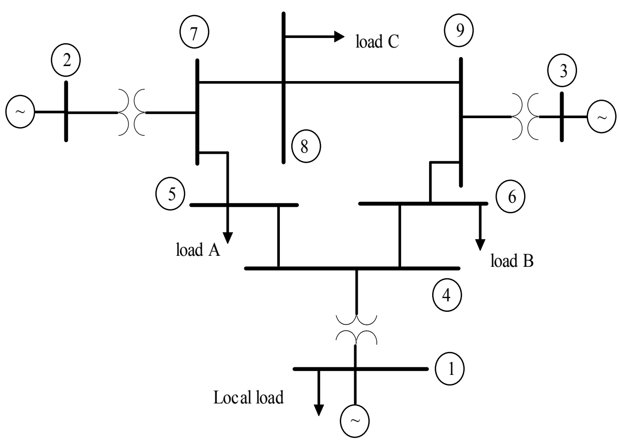

Fig. 10. Multimachine power system.

Table 3. Loading of the system (in p.u)

	Light		Normal case		Heavy	
Generator	P	Q	P	Q	P	Q
G1	0.965	0.22	1.716	0.6205	3.57	1.81
G2	1.0	-0.193	1.63	0.0665	2.2	0.713
G3	0.45	-0.267	0.85	-.1086	1.35	0.43
Load	P	Q	P	Q	P	Q
A	0.7	0.35	1.25	0.5	2.0	0.9
B	0.5	0.3	0.9	0.3	1.8	0.6
C	0.6	0.2	1.00	0.35	1.6	0.65
at G1	0.6	0.2	1.00	0.35	1.6	0.65

Table 4. The controller parameters.

	BFSSSC	PSOSSSC	BSOSSSC
Kp_{dc}	0.7852	1.0964	2.7304
Ki_{dc}	2.1182	0.1332	2.3841
Kp_{ac}	2.2483	2.9877	3.9861
Ki_{ac}	0.0877	1.6774	0.6715
K	0.1297	0.2442	0.1324
T_1	0.8758	0.5972	0.6445
T_3	0.7561	0.4523	0.5847

6.1 Step Response for Normal Load Condition

Figs. 11 and 12 show the responses of $\Delta\omega_{12}$ and $\Delta\omega_{23}$ for a 0.1 step increase in reference voltage of generator (1) for normal loading condition. These figures indicate the capability of the BSOSSSC in reducing the settling time and damping power system oscillations. Moreover, the mean settling time of these oscillations is 2.2*,* 2.7*,* and 3.4 second for BSOSSSC, PSOSSSC, and BFSSSC respectively, so the proposed BSOSSSC is capable of providing sufficient damping to the system oscillatory modes compared with PSOSSSC and BFSSSC.

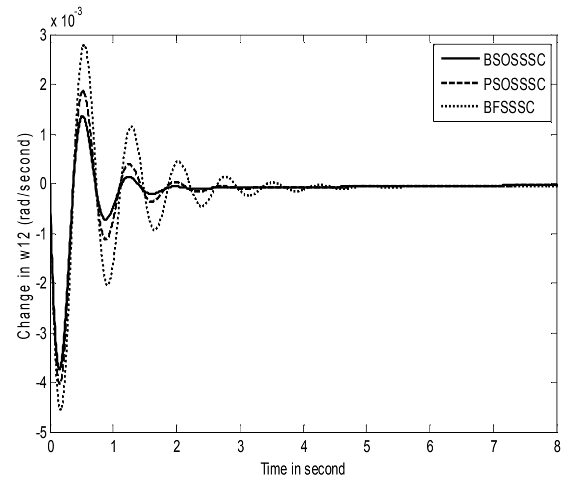

Fig. 11. Change in $\Delta\omega_{12}$ for normal load condition.

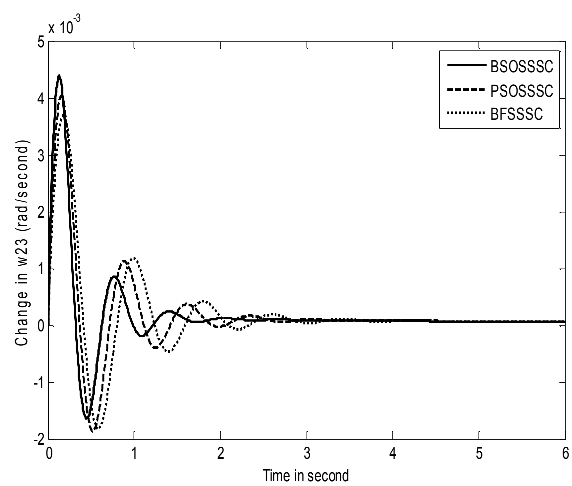

Fig. 12. Change in $\Delta\omega_{23}$ for normal load condition.

6.2 Response under heavy load condition:

Figs. 13 and 14 show the system response at heavy loading condition with fixing the controller parameters. From these figures, it can be seen that the response with the proposed BSOSSSC shows good damping characteristics to low frequency oscillations and the system is more quickly stabilized than PSOSSSC and BFSSSC. The mean settling time of oscillation is 2.0, 2.7, and 3.4 second for BSOSSSC, PSOSSSC, and BFSSSC respectively. Hence, the proposed BSOSSSC extend the power system stability limit.

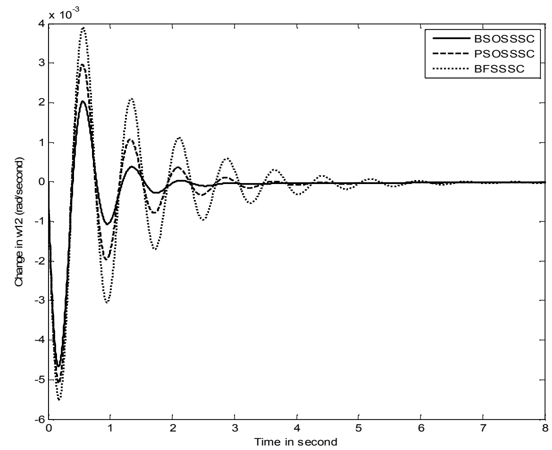

Fig. 13. Change in $\Delta\omega_{12}$ for heavy load condition.

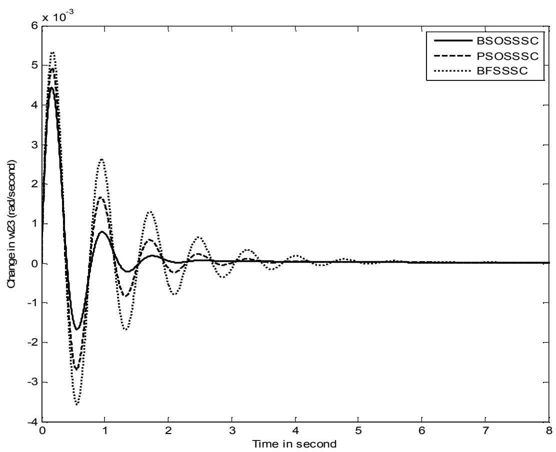

Fig. 14. Change in $\Delta\omega_{23}$ for heavy load condition.

7. Conclusions

In this study, a new optimization algorithm known as BSO, which synergistically couples the BFOA with the PSO for optimal designing of SSSC damping controller is thoroughly investigated for different power systems. For the proposed controller design problem, an integral time absolute error of the speed, DC voltage and transmission line power of SSSC is taken as the objective function to improve the system response in terms of the settling time and overshoots. The superiority of this objective function is that the effect of SSSC signal is taken into consideration. Simulation results are presented for various loading conditions to verify the effectiveness of the proposed controller design approach. Moreover, the proposed control scheme is robust, simple to implement, yet is valid over a wide range of operating conditions.

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Appendix

The system data are as shown below:

a) Synchronous generator (p.u) X_d=1.07, X_q=1.0, X'_d=0.3, τ'_{do}=5.9, H=2.37, Pe=0.9, Vt=1.0.

b) Excitation system K_A =400 and T_A=0.05 sec.

c) Transmission line (p.u), X_{tL}=0.3, X_{LB}=0.3

d) SSSC parameters (p.u), X_b=0.05, V_{DC}=1.0, C_{DC} =1.0.

e) Bacteria parameters: Number of bacteria =10; number of chemotatic steps =10; number of elimination and dispersal events = 2; number of reproduction steps = 4; probability of elimination and dispersal = 0.25; the values of $d_{attract}$ =0.01; the values of $\omega_{attract}$=0.04; the values of $h_{repelent}$=0.01; the values of $\omega_{repelent}$=10.

f) PSO parameters: $C_1 = C_2$ =2.0, ω=0.9.