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Optimal Location of SSSC Based on PSO to Improve Voltage Profile and Reduce Iraqi Grid System Losses

Abstract- *This search aims to study the effects of (SSSC)"static synchronous series compensator– one of the FACTS devices" – on reducing the power losses and improving voltage profile of Iraqi national grid system. Proposed particle swarm optimization ("PSO") to determine the optimum location of "SSSC" devices based objective function that depends on the power and voltage as fitness. The proposed algorithm is checked on the IEEE- 9bus. Then is applied on the Iraqi national grid. The results show the ability of the proposed method to determine the optimum location of static synchronous series compensator (SSSc) that reduced losses of active power and improve the bus "voltage profile". The proposed algorithms are implemented by using MATLAB package version 7.10*

Keywords- *static synchronous series compensator (SSSc), PSO and active power losses.*

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1. Introduction

The demand of electric power has rapidly increased and is anticipated to go on growing while the expansion of power generation has been limited due to resources and environmental limitation, which leads to an augmented stress of the transmission lines and higher risks for faulted lines. Adding a new transmission lines can be one solution for making the system more secure and stable. However, it becomes a time-consuming process due to political and environmental reasons. The Flexible AC Transmission Systems FACTS devices is a new solution to enhance the stability and security of the power system [1].

The raised interest in facts controllers is due to two causes. Firstly, the late evolution in the high power electronics has made facts controllers effective in terms of cost and secondly, raised loading of electrical power systems, incorporated with disarrangement of power industry, induces the utilization of power flow regulate as an extremely cost-effective technique of dispatching determined power transactions[2]. However, the FACTS benefits and performance are depended on their size and location and may be maximized through efficient optimization methods [3]. Several research have been reported in the literature to find the optimum allocation of FACTS using different techniques like artificial neural network, genetic algorithm (GA), simulated annealing (SA), tuba search, and swarm optimization [3-10]. Azadani, et.al. used particle swarm optimization (PSO) to detect optimal allocation and sizing of STATCOMs in the power system network. Allocation of STATCOM is required for voltage profile improvement, and enhance the system load ability [6]. Kumar, et.al. Proposed a method based on (CSO) cat swarm optimization to find the best allocation of FACTS controller in an interconnected power system under contingency for maximize the loadability and voltage stability [7]. Mohammad introduced L- index to detect the best location of shunt fact devices for the iraqi grid to achieve enhancement in voltage profile. STATCOM and SVC were elaborated as the compensation devices [8]. J. Vivekananthan, proposed an effective method to find best optimal location of FACTS controllers using bacterial foraging optimization method. The proposed algorithm is tested on IEEE 30 bus power system. In this work, proposed PSO algorithms to specified optimal location and numbers of SSSc devices to reduce the active power loss and improve voltage profile of Iraqi national super grid.

2. Static Synchronous Series Compensator (SSSC)

The SSSC is a second-generation series compensation equipment of FACTs, becomes more attractive due to its superior abilities. The SSSC has been applied to different power system studies to improve the system performance [11]. The SSSC is a synchronous voltage source that internally generates the desired compensating voltage in series with the line independent of the line current as shown in Figure 1. The series inverter can be applied to

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control the reactive and active power flow and voltage with controllable magnitude and phase in series with the transmission line.

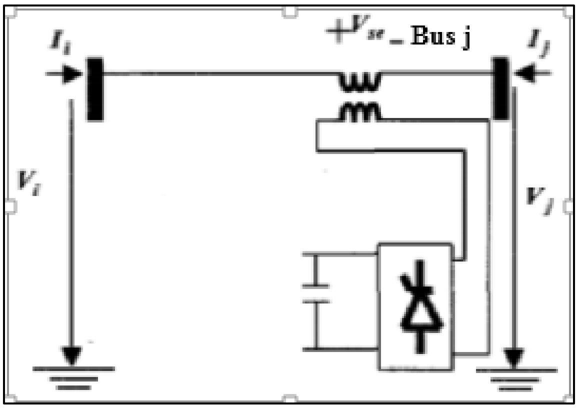


Figure 1: SSSC link in transmission line

The SSSC equivalent circuit is described in Figure 2. The SSSC is represented by a voltage source V_{se} in series with a transformer impedance.

$V_{se} = V_{se}\angle\theta_{se}$, $V_i = V_i\angle\theta i$ and $V_j = V_j\angle\theta j$,

Then the power flow equations of the SSSC are [12].

$$P_{ij} = V_i^2 G_{ii} - V_i V_j\left[G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right] - V_i V_{se}\left[G_{ij}\cos(\theta_i - \theta_{se}) + B_{ij}\sin(\theta_i - \theta_{se})\right] \quad (1)$$

$$Q_{ij} = -V_i^2 B_{ii} - V_i V_j\left[G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right] - V_i V_{se}\left[G_{ij}\sin(\theta_i - \theta_{se}) - B_{ij}\cos(\theta_i - \theta_{se})\right] \quad (2)$$

$$P_{ji} = V_j^2 G_{ii} - V_i V_j\left[G_{ij}\cos\theta_{ji} + B_{ij}\cos\theta_{ji}\right] + V_j V_{se}\left[G_{ij}\cos\left(\theta_j - \theta_{se}\right) + B_{ij}\sin\left(\theta_j - \theta_{se}\right)\right] \quad (3)$$

$$Q_{ji} = -V_j^2 B_{jj} - V_i V_j\left[G_{ij}\sin\theta_{ji} - B_{ij}\cos\theta_{ji}\right] + V_j V_{se}\left[G_{ij}\sin\left(\theta_j - \theta_{se}\right) - B_{ij}\cos\left(\theta_j - \theta_{se}\right)\right] \quad (4)$$

Where; $G_{se} + \mathrm{j}\,B_{se} = \frac{1}{Z_{sc}}$

$G_{ii} = G_{ij} + G_{sh}$,$B_{ii} = B_{ij} + G_{sh}$,$G_{ii} = G_{jj}$,$B_{ii} = B_{jj}$

P_{ij} and Q_{ij}: active and reactive power flowing through bus i to j.

P_{ji} and Q_{ji}: active and reactive power flowing through bus j to i.

G G_{ij} and Bij: conductance and susceptance of line j r, i-j respectively.

G_{ii} and Bii: conductance and susceptance at bus i.

G_{jj} and Bjj : conductance and susceptance at bus j.

V_{se}: synchronous series compensator voltages source.

The SSSC's operating constraint is [12]:

$$PE = \mathrm{Real}\left(V_{se} I_{ji}\right) = 0 \quad (5)$$

$$V_i\,V_{se}\left[B_{ij}\,\mathrm{Sin}(\theta_i - \theta_{se}) - G_{ij}\,\mathrm{Cos}(\theta_i - \theta_{se})\right] - V_j V_{se}\left[B_{ij}\,\mathrm{Sin}\left(\theta_j - \theta_{se}\right) - G_{ij}\,\mathrm{Cos}\left(\theta_j - \theta_{se}\right)\right] = \mathbf{0} \quad (6)$$

Where PE is power exchange via the DC link

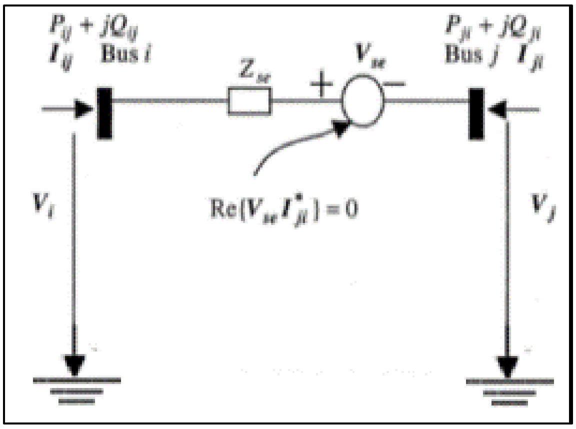


Figure 2: Equivalent circuit of SSSC

3. Particle Swarm Optimization

The Particle swarm optimization **(PSO)** method is one of the methods under the wide category of swarm intelligence methods for solving the problems of optimization. In a PSO system, particles flying around in a several dimensions search space. Through the flight, each particle modify its position according to its own experience (Pbest), and according to the experience of a neighboring particle (gbest) use made of the best position encountered by itself and its neighbor. Assuming v and x are the velocity and position of the particle in a search space, respectively. The best previous position of the ith particle is recorded and presented as $Pbest_i$ The best particle among all the particles in the group is presented by $gbest_d$. The current velocity and position of each particle can be determined using, previous velocity, previous position and current velocity of that particle, as given in [13]:

$$v_{i,g}(u+1) = w * v_{i,g}(u) + c_1 * rand1 * \left(pbest_{i,g}(u) - x_{i,g}(u)\right) + c_2 * rand2 * \left(gbest_g(u) - x_{i,g}(u)\right) \quad (7)$$

$$x_{i,g}(u+1) = x_{i,g}(t) + v_{i,g}(u+1) \quad (8)$$

Where

v_i is the velocity of particle i

u is pointer of iterations

g=1,2,…, M, (g: generation and M is no. of iterations)

i= 1,2,…N, (N is no. of particles)

$Pbest_i$ is the best position of particle i

gbest is best particle among all the particles in the group

c_1 , c_2 are acceleration constants

The range of the velocity must lie in $v_{min} \le v_i^{(u)} \le v_{max}$, Particles may fly past good solutions, if v_{max} is too high, and particles may not explore sufficiently beyond local solutions, if v_{min} is too small. v_{max}

is much set at (10 – 20) % of the dynamic range on each dimension, and the acceleration constants c_1 and c_2 are much set to be 2.0 [13].

The inertia weight w is given as,

$$w = w_{max} - \left[\frac{w_{max} - w_{min}}{Iter_{max}}\right] * Iter \quad (9)$$

Where w_{max} and w_{min} are maximum and minimum values of weighting factor.

$Iter$ and $Iter_{max}$ are current number and maximum number of iterations.

In this work, the particle (solution) is represented transmission line address, which represents a location of SSSC device and the fitness function is the total active power loss, which determined using load flow.

4. Objective Function

The objective of the present work is to minimize the active power losses by optimal positioning of SSSC devices and in the same time, keep the voltage profile within acceptable limits. Hence, the objective function is:

$$Min. (Fun. = \sum P_L) \quad (10)$$

Subject to the following constraints

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} P_{lossij} = 0 \quad (11)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} Q_{lossij} = 0 \quad (12)$$

$$V_{imin} \leq V_i \leq V_{imax} \quad (13)$$

Where

P_{Gi} and Q_{Gi} : active and reactive power generation at bus I P_{Di} and Q_{Di} : active and reactive power demand at bus I

5. Implementation of PSO Algorithm

The locations of SSSC are viewed as a position P in a searching space. In the following steps, we describe the process of the implemented PSO techniques:

1. Input line, bus and SSSC data, number of SSSC, and voltage limits.
2. Initialize the PSO algorithm by setting the number of particles (N), the number of iter- ation (M), the searching range, the c1, c2, and the velocity constraint.
3. Set g=1 for the first generation and randomly generate N particles.
4. Run load flow for all particle and calculate the fitness value of each particle in the g^{th} generation (consider one particle at a time) and determine the position vector of i^{th} particle with the personal best fitness value.
5. Get the velocity and position for each particle according to equation (7) and (8).
6. If iteration number is reach (g>M), determine the selected positions based on obtained P_{best} with the best fitnesst. Else go to step 4, The computational flow chart of the proposed PSO algorithm is demonstrated in Figure 3.

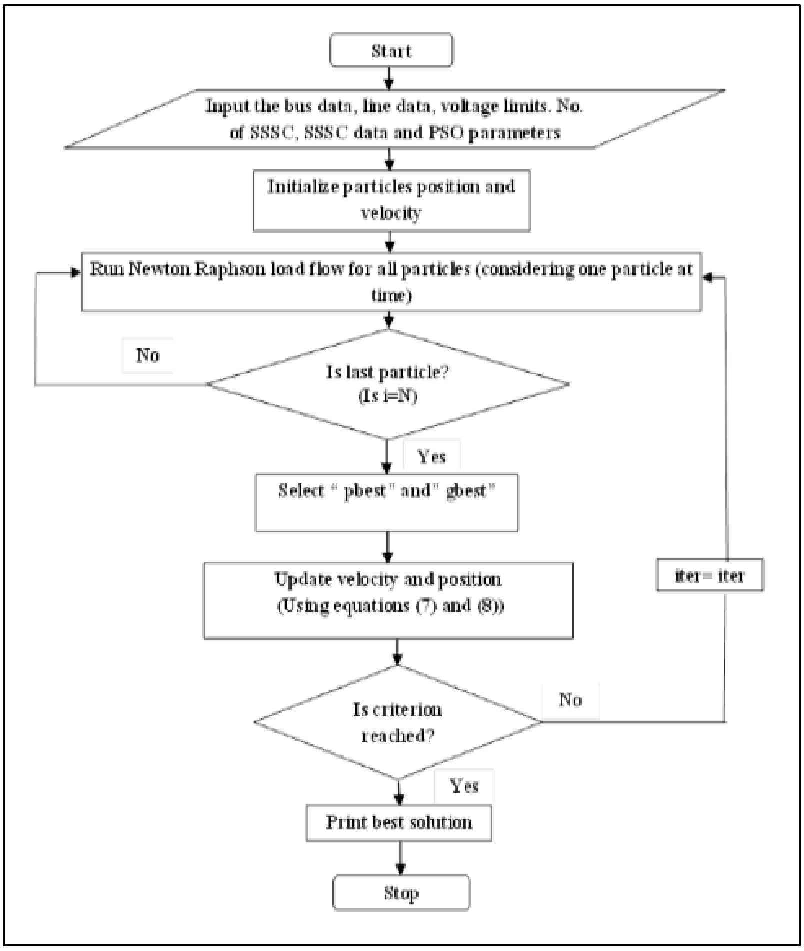


Figure 3: Flowchart of the proposed optimization algorithm

6. Simulation Results and Discussion

IEEE-9bus system and a practical Iraqi National Super Grid (400kV) system are used as the test systems, to declare the effectiveness of the proposed PSO algorithm, The PSO algorithm is implemented in MATLAB 7.10 programming language.

Case (1): IEEE-9bus system

Figure 4 shows the IEEE-9bus system which consists of 6 transmission lines and 9 buses with 3 generation buses and 3 load buses. The bus, line and SSSC data are given in reference [14].
The PSO algorithm is applied to find the optimum position of SSSC that minimizing the real power losses and improve the “voltage profile” of the system. The parameters of PSO technique are shown in the Table 1.
To show the effectiveness of the proposed algorithm, the result are compared with proposed work of ref [14]. The optimal location of SSSC and the total real loss without and with SSSC are given in Table 2.

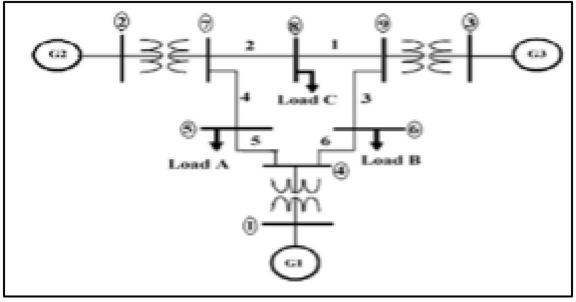


Figure 4: IEEE- 9-bus system

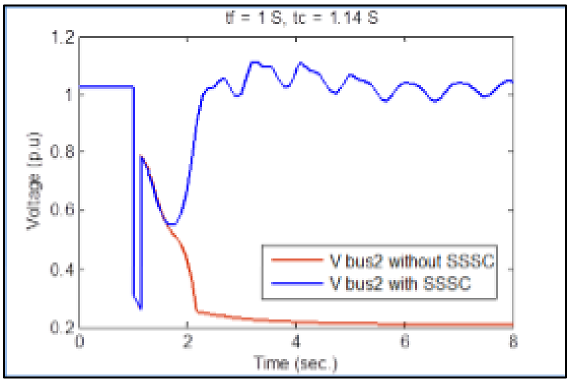
Table 1: Parameters of PSO

Parameters	**Value**
Number of particles	50
Number of iteration	200
c_1	2.5
c_2	1.5
w_{max}	0.9
w_{min}	0.4

Table 2: optimum location, active power loss without and with SSSC

Optimal location	Total real power loss without SSSC [p.u.]	Total real power loss with SSSC using [PSO]	Total real power loss with SSSC [14]
Line 4	0.04641	0.0167.	0.01855

Based on Table 2, it show that the real power losses with the proposed algorithm is reduced about 56% after implement the SSSC. It is also observed that the proposed method gives the best power loss reduction when compared to ref [14] method; this is due to high accuracy and exhaustive search for minimum voltage drop. This result confirms the effectiveness of the proposed PSO. To demonstrate the effectiveness of the SSSC device in enhancing system voltage, time domain simulation is carried out, 3-"phase to ground fault" is applied at line 2. Figures (5-8) show the system bus voltage with and without SSSC. From these figures, it can be seen the contribution of SSSC in enhance the voltage profile, the system without SSSC becomes unstable while it remains stable with existence of SSSC device.



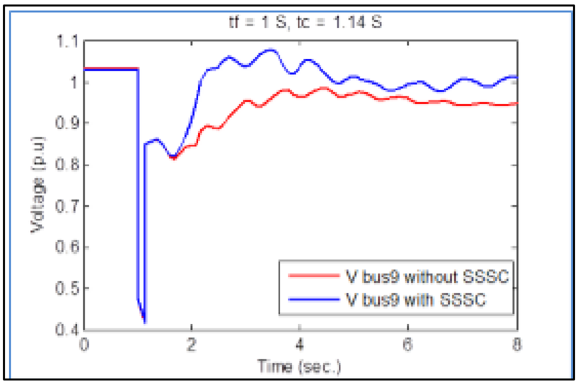


Figure 8: Voltage of bus 9 with and without SSSC

Case (2): Iraqi National Super Grid System

Figure 5: Voltage of bus 2 with and without SSSC

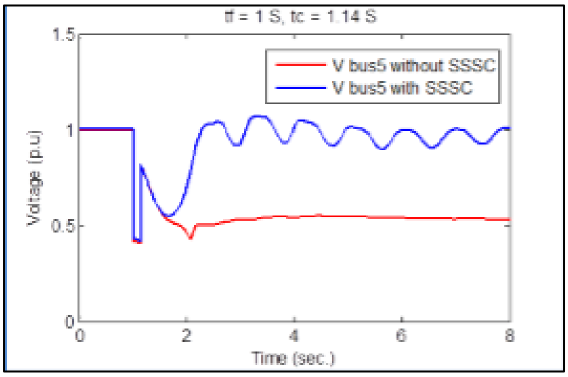


Figure 6: Voltage of bus 5 with and without SSSC

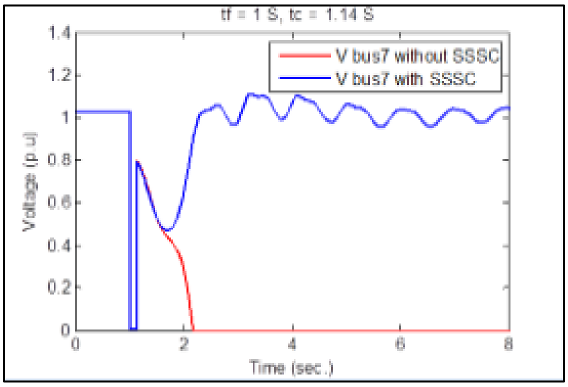


Figure 7: Voltage of bus 7 with and without SSSC

Figure 9 shows the INSGS which consists 24 buses, 11 generation buses, and 19 load buses. In addition, 39 transition lines with total load length of 3750 km. the bus data, line data, generator data, turbine governor data and exciter data are given in Appendix A [10].

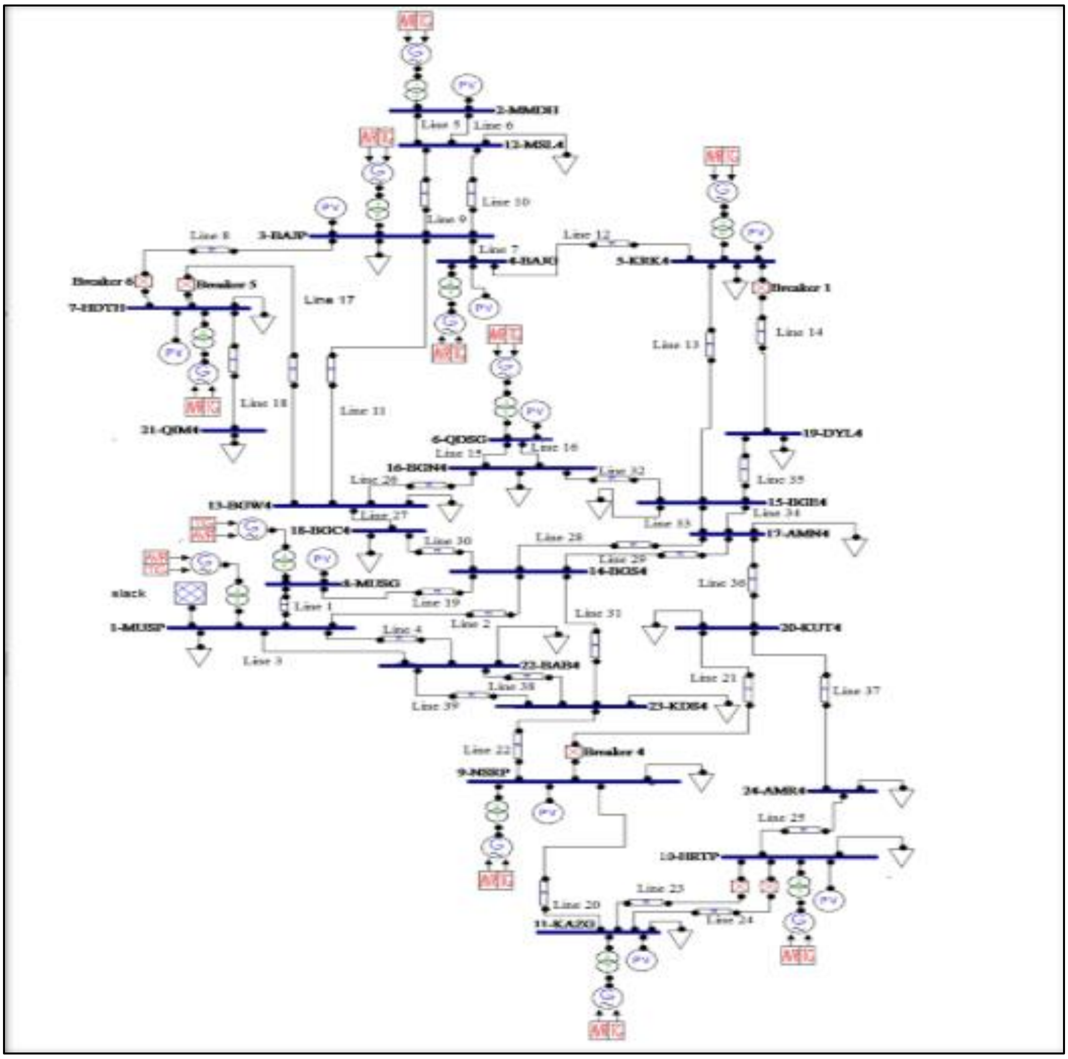


Figure 9: Iraqi national grid (using PSAT)

The proposed PSO algorithm is applied to find the optimal location of three devices of SSSC placed in the INSGS. We assume install three devices of SSSC in the Iraqi network because the SSSC devices are expensive and installing more does not represent significant effect. The optimal location of the SSSC devices, total real losses without and with SSSC are given in Table 3.

Based on the Table 3, it shows that the real power losses with the proposed algorithm are reduced about 44% after implement the SSSC. This result confirms the effectiveness of the proposed PSO. To demonstrate the effectiveness of the SSSC device in enhancing system voltage, time domain simulation is carried out, 3-“phase to ground fault” is applied at different locations (near NSRP bus at line 21 and near bus KRK4 at line 14) with different fault duration. Figures (10-16) show the bus voltage with and without SSSC. From these figures, it can be seen the contribution of SSSC in enhancing the voltage profile, the system without SSSC becomes out of oscillation range (unstable) while it remains stable with the existence of SSSC device. Figures (14–16) show that when increasing the duration time of

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fault (time clearance of fault t_c). The system remains stable with the existence of SSSC. Also, it is clear from figures (12)and (14)the SSSC devices which placed in the optimal location not only improved the voltage profiles of near buses to link devices but the improvement includes remote buses.

Table 3: optimum location of SSSC, active power loss without and with SSSC

Optimal location of SSSC	Total real power loss without SSSC [p.u.]	Total real power loss with SSSC using [PSO]
Line 11, line 20 and line 36	0.48095	0.26931

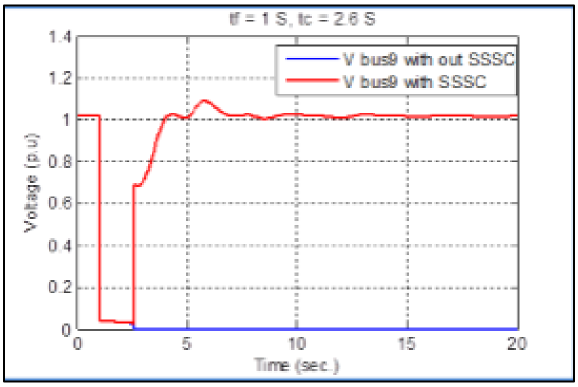

Figure 10: Voltage of bus 9-NSRP with and without SSSC (Fault near bus NSRP at line 21)

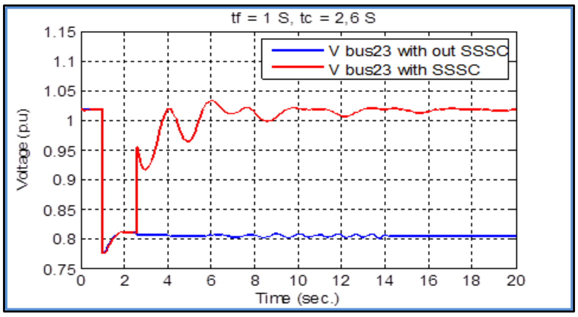

Figure 11: Voltage of bus23- KUT4- with and without SSSC (Fault near bus NSRP at line 21)

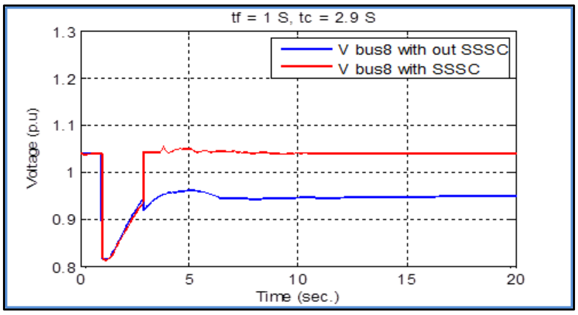

Figure 15: Voltage of bus8- QDSG- with and without SSSC (Fault near bus KRK4 at line 14)

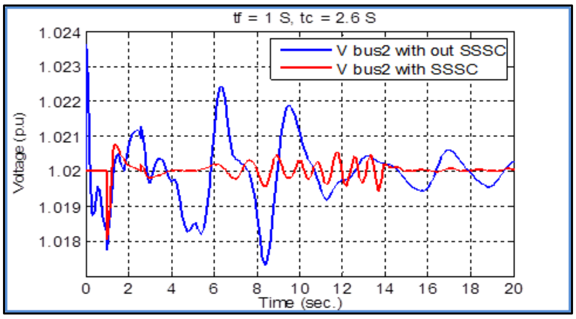

Figure 12: Voltage of bus2-MMDH- with and without SSSC (Fault near bus NSRP at line 21)

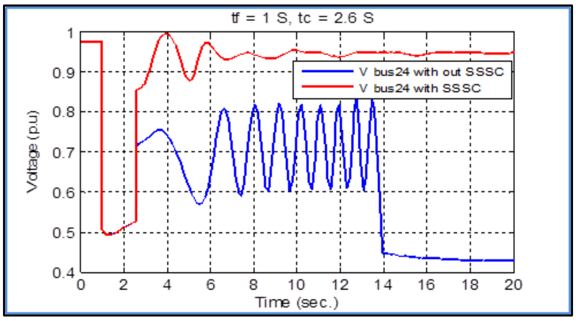

Figure 13: Voltage of bus24- AMR4- with and without SSSC (Fault near bus NSRP at line 21)

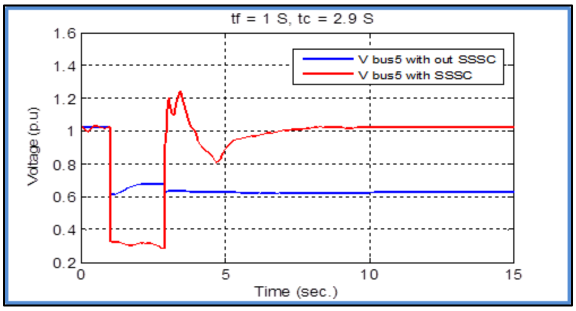

Figure 14: Voltage of bus5- KRK4- with and without SSSC (Fault near bus KRK4 at line 14)

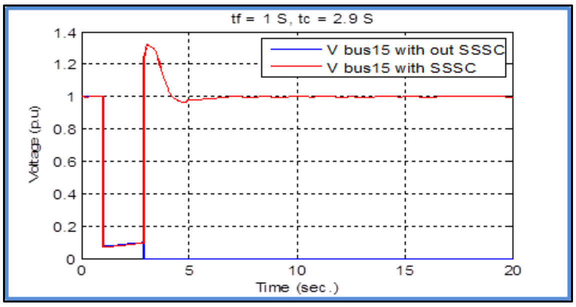

Figure 16: Voltage of bus15- BGE4- with and without SSSC (Fault near bus KRK4 at line 14)

7. Conclusion

This work proposed particle swarm optimization (PSO) based approach for allocation of the“(SSSC) static synchronous series compensator devices” to obtain the minimum real power losses of the system. The optimal locations of SSSC are specified for IEEE 9 – bus system in line 4 and for Iraqi national super grid system in lines 11, 20, and 36. The results showed a great reduction in the real power losses. It is also observed that the SSSC has a good effect in improving the “voltage profile” under a severe type of faults (3-phase to ground) and the system with SSSC devices remain stable even after increasing fault duration time. The SSSC devices that placed in the optimal location not only improved the voltage profiles of near buses to link devices but the improvement includes remote buses.

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Author biography

Dr. I.I. Ali received her B.S. degree in Electrical Engineering from Electrical Engineering Department, University of Technology, Baghdad, Iraq in 1996. She received her M.Sc. degree and Ph.D. degree in Power System Engineering from Electrical Engineering Department, University of Technology, Iraq in 2001 and 2009, respectively.

Currently, she is lecturer at the University of Technology. Her research interests include power system stability, power system control, FACTs devices, power quality improvement and renewable energy.

Table (A-1): Line data for Iraqi power grid (400 kV)[10]

From Bus	To Bus	Line R (pu)	Line X (pu)	Charging (pu)
20	2	0.00144	0.01177	0.36439

20	2	0.00144	0.01177	0.36439
20	3	0.0042	0.03437	1.06426
20	3	0.0042	0.03437	1.06426
3	4	0.00002	0.0002	0.00584
3	13	0.00483	0.04393	1.30165
3	13	0.00496	0.04511	1.33667
3	7	0.00345	0.03132	0.92808
4	5	0.0018	0.01635	0.48447
5	15	0.005114	0.046492	1.377532
5	12	0.004247	0.038612	1.144052
13	14	0.00093	0.00847	0.25099
13	17	0.000616	0.005608	0.166179
13	7	0.00485	0.04405	1.30515
18	19	0.00082	0.00749	0.22181
18	19	0.00082	0.00749	0.22181
18	17	0.000964	0.008772	0.259921
18	1	0.00122	0.01015	0.31897
18	6	0.001094	0.009106	0.286176
18	22	0.00308	0.02795	0.82827
15	14	0.00029	0.00262	0.07763
15	19	0.00043	0.00394	0.11674
15	19	0.00043	0.00394	0.11674
15	12	0.00087	0.00788	0.23348
14	8	0.00015	0.00138	0.04086
14	8	0.00015	0.00138	0.04086
19	23	0.02744	0.22904	0.09156
23	11	0.00432	0.03928	1.1639
23	24	0.00479	0.04354	1.28998
7	16	0.00292	0.02391	0.74035
1	6	0.000125	0.001043	0.032791
1	21	0.00081	0.00673	0.21165
1	21	0.00081	0.00673	0.21165
21	22	0.00233	0.01935	0.60812
21	22	0.00233	0.01935	0.60812
22	11	0.00383	0.03485	1.03256
11	9	0.00439	0.03993	1.18316
24	10	0.0029	0.0264	0.78216
10	9	0.00118	0.01076	0.3187
10	9	0.00118	0.01076	0.3187

Table (A-2): Bus data for Iraqi power grid (400 kV)

Bus No.	Bus Name	Voltage (pu)	PL (MW)	QL (Mvar)	Pg (MW)
1	MUSP	1.0400	199.779	116.6333	1107.1
2	MMDH	1.0200	0.0000	0.0000	690.10
3	BAJP	1.0250	124.862	92.2467	406.00
4	BAJG	1.0250	0.0000	0.0000	590.45
5	KRK4	1.0217	129.8567	60.4896	239.87
6	MUSG	1.0400	0.0000	0.0000	369.00

7	HDTH	1.0300	253.054	75.612	202.97
8	QDSG	1.0075	0.0000	0.0000	735.30
9	KAZG	1.0096	566.0419	294.6579	207.58
10	HRTP	1.0150	154.8291	72.1171	332.13
11	NSRP	1.0197	422.8665	198.3219	775.00
12	DYL4	1.0000	83.2415	21.1712	0.0000
13	BGW4	1.0000	576.031	302.4481	0.0000
14	BGN4	1.0000	412.8776	139.1261	0.0000
15	BGE4	1.0000	849.0627	294.6579	0.0000
16	QIM4	1.0000	109.8787	39.3182	0.0000
17	BGC4	1.0000	49.9449	181.4688	0.0000
18	BGS4	1.0000	0.0000	0.0000	0.0000
19	AMN4	1.0000	126.564	56.0014	184.52
20	MSL4	1.0000	649.2833	302.4481	0.0000
21	BAB4	1.0000	307.9934	184.6695	0.0000
22	KDS4	1.0000	213.0981	151.4458	0.0000
23	KUT4	1.0000	259.7134	108.1756	0.0000
24	AMR4	1.0000	311.0221	160.3709	0.0000