A Review on Social Group Optimization Technique for Power Capability Enhancement with Combined TCSC-UPFC

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1 Introduction

With the demand for electrical power increasing every year, the electric supply industry has undergone an extreme and overwhelming transformation worldwide. Due to the ever-changing load pattern, the conventional generating stations like hydro, thermal, nuclear as well as renewables like wind, solar, geothermal, tidal, etc., are installed to meet the consumer's demand. The power generated by these stations needs transmission lines to connect the generating stations to load centers [1, 2]. While transmitting power, some transmission systems may be overloaded, loaded to the full capacity, or may not be loaded to the full capacity. Consequently, the system voltage profile deteriorates, and in some extreme cases, the system may collapse affecting the security of the system.

Power system operators use FACTS-based solutions to maintain the stability of the system. These devices operate to control different electrical parameters in the transmission networks. There are many types of power electronic controllers used in FACTS [3]. These controllers operate very fast and are powerful in maintaining the stability limit in the transmission system. UPFC and TCSC are considered as the most efficient controllers among the different FACTS controllers. UPFC controls the power flow in the system by compensating the line impedance, voltage magnitude,

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and phase angle. TCSC also provides efficient power flow control in addition to fault current limitation at some point. It is economical in terms of cost for solving various stability problem.

Optimal allocation of FACTS is particularly important in power system for its economic effectiveness and system performance. To get the maximum benefits, FACTS devices of suitable types should be placed at the most appropriate location. Various optimization techniques like evolutionary programming (EP) [4], optimal power flow (OPF) [5], genetic algorithm (GA) [6], teaching learning-based optimization (TLBO) [7], particle swarm optimization (PSO), biogeography-based optimization (BBO), and weight-improved particle swarm optimization (WIPSO) [8] have been utilized to solve the allocation problem. Social group optimization (SGO) is another method which can be used to solve for locating the FACTS devices [1].

2 Articulation of the Problem

2.1 Intent of the Optimization

Real power losses P_L and net voltage deviation (NVD) affect the operation of transmission line. The reduction of both helps in enhancing stability during transmission. Hence, the objective function (OF) is written as

$$OF = W_1 * P_L + W_2 * NVD \tag{1}$$

where W_1 and W_2 are weight factors of loss and, Knowing conductance G of the line joining buses i and j **whose voltages are** V_i and V_j, δ_{ij} and NLB being phase difference between the buses voltages and total number of buses, respectively, the real power loss is expressed as

$$P_L = \sum_{j=1}^{NLB} G(V_i^2 + V_j^2 - 2V_i V_j \cos \delta_{ij} \tag{2}$$

If VD_i is the potential deviation at bus I, the net voltage deviation is

$$NVD = \sum_{j=1}^{NBL} VD_i \tag{3}$$

where

$$VD_i = \begin{cases} 0 \text{ if } 0.95 < V_i < 1.05 \\ (1 - V_i)^2 \text{if } 0.9 < V_i < 0.95 \text{ or } 1.05 < V_i < 1.10 \\ 5 * (1 - V_i)^2 \text{if } V_i < 0.9 \text{ or } V_i > 1.1 \end{cases}$$

2.2 Equality Constraints

The equality constraints in the transmission line are as follows:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NLB} V_j (G \cos \delta_{ij} + B \sin \delta_{ij}) = 0 \tag{4}$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NLB} V_j (G \cos \delta_{ij} - B \sin \delta_{ij}) = 0 \tag{5}$$

In Eqs. (4) and (5), P_{Gi} and P_{Di} are the active power generation and requirement, respectively, V_i and V_j are the absolute voltage values at buses i and j. G and B are the properties of transmission lines (what properties? Be specific), and $\delta_{ij}=$ is the phase difference between the bus voltages [2].

2.3 FACTS Devices Considered

Two FACTS devices have been considered in the present study, namely TCSC and UPSC. Brief description of them is presented below.

3 Social Group Optimization (SGO)

3.1 Overview of Social Group Optimization

Satapathy and Naik have developed social group optimization technique by impersonating the behavior and knowledge in human groups, for example, behavioral traits on human life like honesty, fear, tolerance, etc. In SGO, each person in the population has some knowledge on solving the complex problem, and the remaining persons in the group acquire knowledge through that person in the group. The person having knowledge is known as best person or best solution. The best person propagates knowledge among the entire persons involved in the group improving their knowledge level. This technique has improving phase and acquiring phase. The improving

phase synchronizes the positions of people, and the acquiring phase allows the person in that group to discover the best solution for the population under concern. The optimization technique is formulated mathematically as [9]:

Let X_i be considered as the initial knowledge of persons in the group and $i = 1, 2, 3, \ldots, N$ with N being the total number of persons in the group. The best person who is identified as g_{best} in the population tries to pass on the knowledge to all persons which will eventually improve the knowledge in the group.

Hence,

$$g_{best} = \min\{f_i, i = 1, 2, \ldots, N\} \tag{7}$$

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The updated position or knowledge of every population in the group is expressed by the following relation:

$$X_{new_{ij}} = c * X_{old_{ij}} + r * \left(g_{best}(j) - X_{old_{ij}}\right) \tag{8}$$

where X_{new} is the new knowledge, X_{old} is the old knowledge, G_{best} is the best knowledge, r is the random number in the range [0, 1], and c is the self-introspection parameter which can be set from [0,1].

In the acquiring phase, the person will find the global solutions based on knowledge updating in the improving phase. Here, select one person from the group (X_r) based on i not equal to r. Once the fitness value becomes $f(X_i) < f(X_r)$, then following procedure is followed:

$$X_{new_{i,j}} = X_{old_{i,j}} + r_1 * \left(X_{i,j} - X_{r,j}\right) + r_2 * \left(g_{best_j} - X_{i,j}\right) \tag{9}$$

Here, r_1 and r_2 are random number in the range [0, 1]. Using trial-and-error approach, r_1 and r_2 is set as 0.4 and 0.2. $X_{r,j}$ is the knowledge value of the chosen individual.

The SGO algorithm is illustrated in Fig. 1, where the person shown inside the circle is the one with best knowledge or g_{best}.

3.2 OPF with FACTS Devices by Social Group Optimization

SGO is implemented to determine the location of FACTS devices. The proposed method is listed below and is also shown in Fig. 2.

Step 1: Initialization of population and design variables. Population N is assigned as $N = 6$ for 6 bus system, $N = 14$ for 14 bus system, and $N = 57$ for 57 bus system. Similarly, design variable indicates the total number of FACTS devices to be included in the particular bus system.
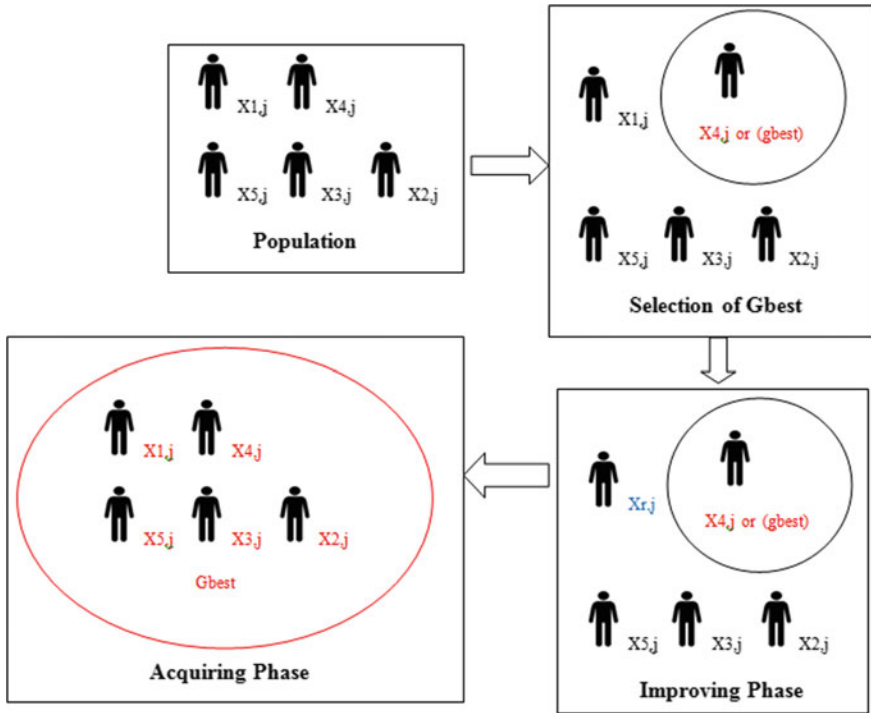
Fig. 1 Basic understanding of SGO

Step 2: Performing the base case load flow. This step involves to solve base case power flow by Newton–Raphson power flow method.

Step 3: Identifying g_{best} and calculating the fitness function. The g_{best} is considered best value calculated from the step 2, and fitness function is calculated using Eq. (3) in terms of net voltage deviation.

Step 4: Improving and acquiring phase. The best value is compared with other population using the Eqs. (8) and (8). The g_{best} is updated accordingly.

Step 5: Solving power flow with FACTS device. This step solves the power flow once again after the inclusion of multi-type FACTS devices—TCSC and UPFC.

4 Result and Discussion

The solution to find optimal allocation of FACTS controllers to minimize the losses and voltage deviation for the IEEE-6, IEEE-14, and IEEE-57 bus systems is obtained and discussed. The simulation was carried out by MATLAB software.
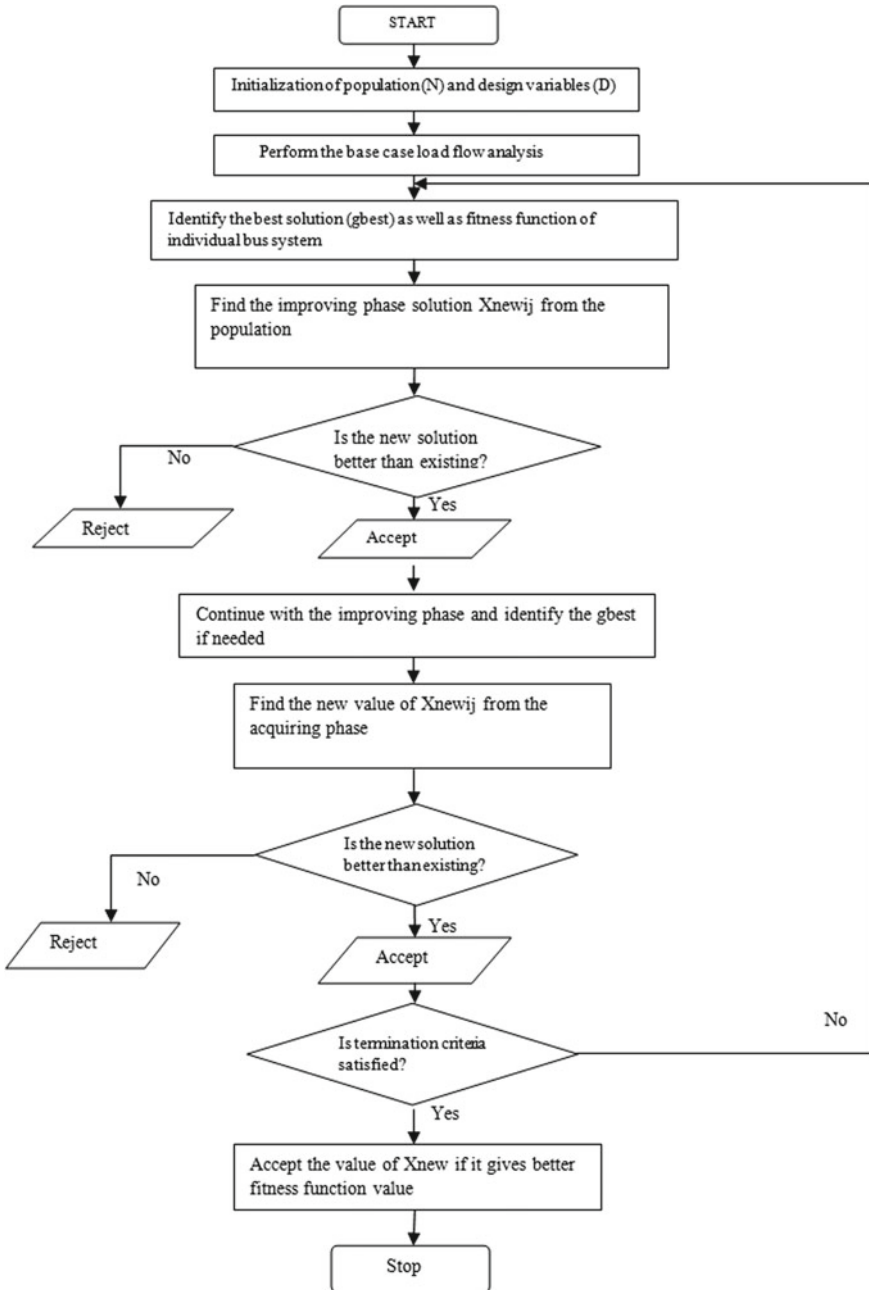
Fig. 2 Implementation of social group optimization

Table 1 Location of UPFC and voltage profile with/without FACTS (IEEE-6)

Bus number	Device connected	Voltage (p.u) without facts	Voltage (p.u) with facts after SGO
1		1	1
2		1	1
3	**UPFC**	**1.0819**	**1.04378**
4		1.0239	1.00064
5		0.9543	0.96256
6		0.95232	0.95484

Table 2 Location of TCSC and line flows before and after FACTS devices (IEEE-6)

From bus	To bus	Device connected	P flow without facts	Q flow without facts	P flow with facts	Q flow with facts	P loss without facts	P loss with facts
1	2	–	0.0071	−0.00227	−0.00258	0.00015	0	0
2	**3**	**TCSC**	**−0.20246**	**−0.11628**	**−0.95886**	**−0.46862**	**0.00544**	**0**
3	4	–	0.0921	0.05761	0.28445	1.62019	0.00202	0
5	**4**	**TCSC**	**−0.27992**	**−0.11906**	**−0.90740**	**−0.43997**	**0.01016**	**0**
6	5	–	0.01348	−0.01137	0.00512	−0.02094	7e−05	0.0010
2	5	–	0.10956	0.04969	0.10452	0.03520	0.00289	0.00243
1	6	–	0.32518	0.10618	0.31601	0.09541	0.0117	0.01090

4.1 IEEE-6 Bus System

The allocation of the FACTS controllers is identified from SGO algorithm. Three numbers of FACTS controllers; one UPFC and two TCSC are used for 6 bus system. In order to do so, the self-retrospective coefficient c in Eq. (7) is chosen as 0.2. Similarly, the value of r_1 and r_2 in equation is taken as 0.2 and 0.4 based on trial-and-error approach. After performing the algorithm successfully, we were able to identify the location of UPFC at bus number 3 and two TCSC at lines 2–3 and 5–4. Table 1 shows the impact of UPFC in improving the voltage profile of not only bus number 3 but also the overall system. Table 2 shows the addition of TCSC on the line 2–3 and 5–4 which minimizes the active power loss to a very low number.

4.2 IEEE-14 Bus System

The 14 bus and line data are standard IEEE data. Four FACTS devices—two UPFC and two TCSC—are used for this system. After implementing the algorithm, we were

able to identify the location of UPFC at bus numbers 2 and 14. Similarly, TCSC was placed at line 2–3 and line 5–4.

Table 3 shows the impact of UPFC. The voltage level at bus number 2 after inserting UPFC is almost similar to the voltage level without UPFC. However, the voltage level at bus number 14 is drastically improved after the insertion of UPFC. Similarly, Table 4 shows the impact of TCSC in minimizing the active power losses at lines 2–3 and 5–4. Figure 3 shows the voltage profile of the IEEE-14 bus system with and without FACTS controllers. Similarly, Fig. 4 compares the active power loss before the insertion of FACTS device and after the FACTS device. In all the case, it is observed that these FACTS devices improve the voltage profile and line

Table 3 Location of UPFC and voltage profile with/without FACTS (IEEE-14)

Bus number	Device connected	Voltage (p.u) without facts	Voltage (p.u) with facts after SGO
1	–	1.06	1.06
2	**UPFC**	**1.045**	**1.04**
3	**–**	**1.0**	**1.0**
4	–	1.0027	1.0108
5	–	1.0066	1.007
6	–	1.0	1.0
7	–	1.0043	1.005
8	–	1.0	1.0
9	–	0.99885	1.00017
10	–	0.99117	0.99228
11	–	0.99187	0.99246
12	–	0.98509	0.98661
13	–	0.98082	0.98387
14	**UPFC**	**0.97181**	**0.98485**

Table 4 Location of TCSC and line flows with/without FACTS (IEEE-14)

| From bus	To bus	Device connected	P without facts	Q without facts	P with facts	Q with facts	P loss without facts	P loss with facts
1	2	–	1.5823	−0.19236	1.56608	−0.18857	0.04473	0.04282
1	5	–	0.72748	0.27835	0.69224	0.27065	0.00298	0.00269
2	**3**	**TCSC**	**0.73676**	**0.1004**	**1.83575**	**0.79844**	**0.02388**	**0**
2	5	–	−0.40845	−0.08489	−0.37238	−0.09521	0.0097	0.0082
5	**4**	**TCSC**	**0.6208**	**−0.09785**	**0.71228**	**−0.10989**	**0.0052**	**0**
5	6	–	0.43618	0.34666	0.42192	0.34927	0.0031	0.00257
12	13	–	0.01522	0.00422	0.0124	−0.00017	6e−05	0.0003
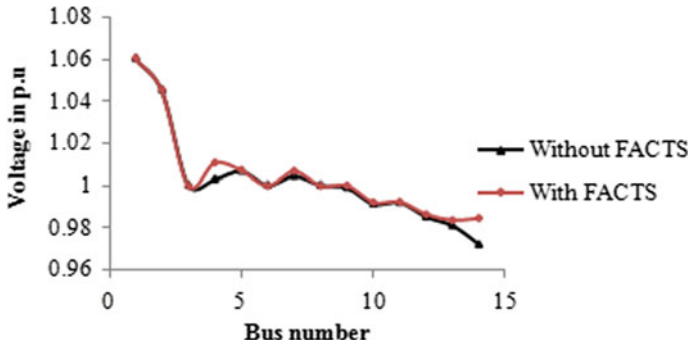
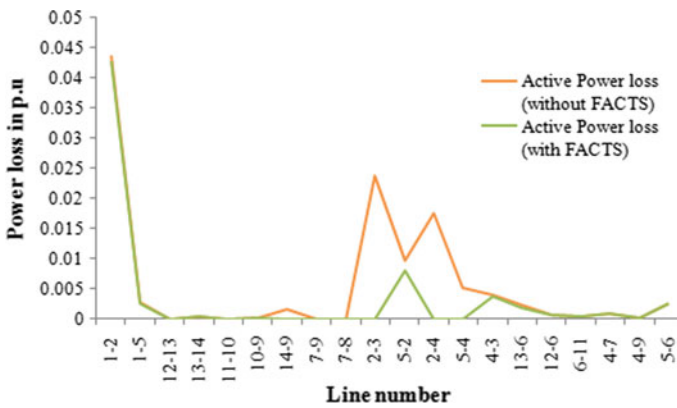**Fig. 3** Voltage profile of IEEE-14 with and without FACTS

Fig. 4 Comparison of power loss before and after FACTS devices

flows of the system enhancing system security and minimizing voltage deviations and line loadings.

4.3   IEEE-57 Bus System

In this scenario, eight FACTS devices—five UPFC and three TCSC—are used. After performing the algorithm, we were able to locate UPFC at bus numbers 21, 25, 26, 27, and 31, while TCSC is located at line numbers 12–13, 14–15, and 22–23. Table 5 shows the impact of UPFC in maintaining the voltage level at bus numbers 21, 25, 26, 27, and 31. The worst-case scenario is observed at bus number 31 as its voltage limit before inserting UPFC is 0.87408 and is under limit. Not only the voltage level at bus 31 improved but also the voltage profile of the overall system is improved. This can be seen at Fig. 5. Similarly, we can observe from Table 6 that the use of TCSC

Table 5 Location of UPFC and voltage profile with/without FACTS (IEEE-57)

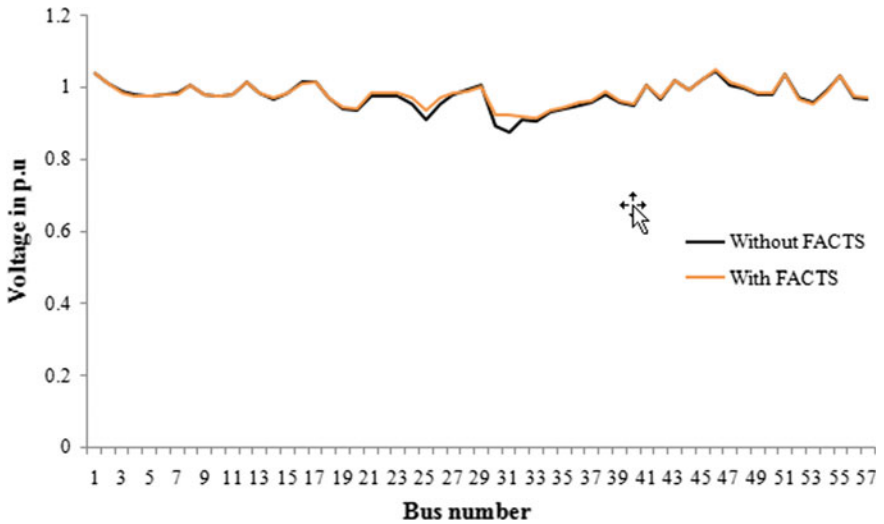| Bus number	Device connected	Voltage (p.u) without facts	Voltage (p.u) with facts after SGO
1	–	1.04	1.04
7	–	0.98166	0.9818
9	–	0.98	0.98
10	–	0.97547	0.97611
11	–	0.97798	0.9794
15	–	0.98382	0.9835
18	–	0.97051	0.97158
19	–	0.94012	0.94473
21	**UPFC**	**0.97439**	**0.9824**
24	–	0.95273	0.97056
25	**UPFC**	**0.90743**	**0.93618**
26	**UPFC**	**0.95389**	**0.97289**
27	**UPFC**	**0.97653**	**0.98256**
31	**UPFC**	**0.87408**	**0.92411**
52	–	0.96913	0.9669
57	–	0.96668	0.97189

Fig. 5 Voltage profile of IEEE-57 with and without FACTS

Table 6 Location of TCSC and line flows with/without FACTS (IEEE-57)

| From bus	To bus	Device connected	P without facts	Q without facts	P with facts	Q with facts	P loss without facts	P loss with facts
1	2	–	0.88029	0.85856	0.9754	0.83223	0.0116	0.01262
3	4	–	0.61759	0.10879	0.56054	0.05841	0.00454	0.00367
9	12	–	0.03824	−0.12404	0.02327	−0.12101	0.00114	0.00102
11	13	–	−0.06285	−0.06179	−0.00947	−0.05541	0.00018	7e−05
12	**13**	**TCSC**	**−0.14121**	**0.64539**	**−0.18069**	**0.8588**	**0.00754**	**0**
13	15	–	−0.5036	−0.0072	−0.43218	0.15922	0.00709	0.0059
14	**15**	**TCSC**	**−0.63894**	**−0.23802**	**−0.94229**	**−0.28349**	**0.00843**	**0**
21	22	–	0.00598	0.0567	−0.0179	−0.00142	0.00035	2e−05
22	**23**	**TCSC**	**−0.00518**	**−0.07547**	**0.0865**	**0.05387**	**9e−05**	**0**
23	24	–	−0.06826	−0.0977	0.03662	0.05915	0.00356	0.00084
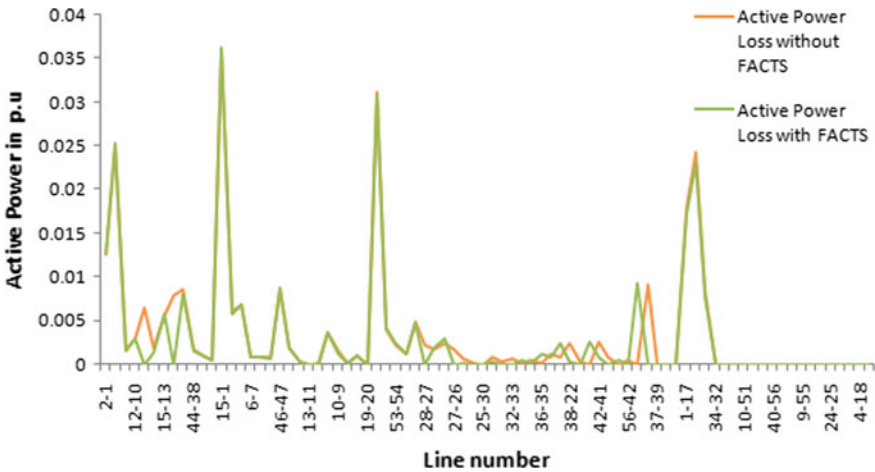
Fig. 6 Comparison of power loss before and after FACTS devices (IEEE-57)

has clearly improved the line flows and minimized the losses. This can be observed at Fig. 6. Overall, the complete system has enhanced their security by minimizing losses and maintaining voltage limit.

5 Conclusion

In this paper, the locations of FACTS devices are found by using the SGO technique to attain the maximum benefit. Simulations were performed on the IEEE-6, IEEE-14,

and IEEE-57 buses, and the results found were recommended. This work observed the new technique for optimal location of FACTS device and the effectiveness of these devices in terms of minimizing the active power losses and load voltage deviation. We can conclude from this work that the installation of FACTS devices using SGO is beneficial for power system restructuring.

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