Buletin Teknik Elektro dan Informatika
(Bulletin of Electrical Engineering and Informatics)
Vol.1, No.2, June 2012, pp.139~150
ISSN: 2089-3191

Congestion management Incorporation of FACTS Devices Using Ant Colony Optimization

Prakash Burade[1], Dr.J.B.Helonde[2]
[1]Head of Electrical Department, ITMCOE, Nagpur, India
[2]Principal & Head of Campus, ITMCOE, Nagpur, India
e-mail: prakash.burade@gmail.com[1], drjbhelonde@itm.edu[2]

Abstract

This paper presents Ant Colony Algorithm (ACA) based approach for the allocation of FACTS (Flexible AC Transmission System) devices for the improvement of Power transfer capacity in an interconnected Power System. The ACA based approach is applied on IEEE 30 BUS System. The system is reactively loaded start from base to 200% of base load. FACTS devices are installed in the different locations of the power system and the system performance is noticed with and without FACTS devices. First, the locations where the FACTS devices to be placed is determined by calculating active and reactive power flows in the lines. Ant Colony Algorithm then applied to find the amount of magnitudes of the FACTS devices. This approach of ACA based placement of FACTS devices is tremendous beneficial both in terms of performance and economy is clearly observed from the result obtained.

Keywords: *FACTS Devices, Line Power Flow, Optimal Location of FACTS Devices, Ant Colony Algorithm.*

1. Introduction

Recently, FACTS technology has become a very effective means to enhance the capacity of existing power transmission networks to their limits without the necessity of adding new transmission lines. Better utilization of existing power system capacities is possible by connecting FACTS devices in the transmission network. By introduction FACTS devices, flexible power flow control is possible. It is known that the power flow through an ac transmission line is the function of line impedance, the magnitude and the phase angle between the sending end and the receiving end voltages. By proper utilization of UPFC (Unified Power Flow Controller), TCSC (Thyristor controlled Series Capacitor), SVC (Static Var Compensator) in the power system network, both the active and reactive power flow in the lines can be controlled. The additional flexibility of power flow using FACTS devices must lead to a net economic gain despite the high cost of FACTS devices. Tighter control of power flow and the increase use of transmission capacity by FACTS devices are discussed in [1]. A scheme of power flow control in lines is discussed in [2]. The use of static phase shifters and FACTS controllers for the purpose of increasing power transfer capacity in the transmission line is described in [3] & [4]. In [5] authors have discussed about the power flow control in transmission network. For the modeling and selection of possible locations for the installation of FACTS devices have been discussed in [6]. The assessment and impact on power networks by the use of FACTS devices have been discussed in [7] through the concept of steady state security regions. A hybrid Genetic Algorithmic approach with FACTS devices for optimal power flow is dealt in [9].

In a congested power system, first, the locations of the FACTS devices were decided based on the sensitivity factors and dispatch problem was solved in [10]. How the unified power flow controllers can be used in a congested power system is discussed in [11]. Genetic Algorithm based separate & simultaneous use of TCSC (Thyristor Controlled Series Capacitor), UPFC (Unified Power Flow Controller),TCVR (Thyristor Controlled Voltage regulator), SVC (Static Var Compensator) were studied in [12] for increase power flow. The objective of this present work is the optimal allocation of FACTS devices in the transmission network, so the transmission loss becomes minimize and also for the simultaneous increase of power transfer capacity of the transmission network. Minimization of transmission loss is a problem of reactive power optimization and can be done by controlling reactive generations of the generators,

Received March 17, 2012; Revised May 22, 2012; Accepted May 28, 2012

controlling transformer tap positions and adding shunt capacitors in the weak buses [13] but the active power flow pattern can not be controlled. In the proposed work, first the locations of the FACTS devices are identified by calculating different line flows. Voltage magnitude and the phase angle of the sending end buses of the lines where major active power flow takes place are controlled by UPFC. TCSC's are placed in lines where reactive power flows are very high and the SVC's are connected at the receiving end buses of other lines where major reactive power flows take place. An Ant Colony Algorithm based approach considering the simultaneous effect of the three types of the FACTS devises are presented and the effectiveness of this technique is clearly evident from the shown result.

2. Facts Devices

2. A. Modeling of FACTS Devices

Mathematical modeling of FACTS devices is required for the steady state analysis. Here the FACTS devices used in the transmission network are UPFC, TCSC and SVC.

- **UPFC**

A series inserted voltage and phase angle can be modeled for UPFC. The inserted voltage has the maximum magnitude of 0.1Vmax, where Vmax is the maximum voltage of the transmission line. The working range of the UPFC angle is between -180 degree and +180 degree.

- **TCSC**

By modifying the line reactance TCSC acts as either inductive or capacitive compensator. The maximum value of the capacitance is fixed at -0.8 XL and 0.2XL is the maximum value of the inductance, where XL is the line reactance.

- **SVC**

The SVC can be operated as either inductive or capacitive compensation. It can be modeled with two ideal switched elements in parallel; one capacitive and one inductive. So, the function of the SVC is either to inject reactive power to bus or to absorb reactive power from the bus where it is connected.

2. B. FACTS Devices Cost Functions

According to [14], Cost functions for SVC, UPFC and TCSC are given below:

UPFC:

$$C_{UPFC} = 0.0003R^2 - 0.2691R + 188.22 \text{ (US \$/kVar)} \qquad (1)$$

TCSC:

$$C_{TCSC} = 0.0015R^2 - 0.7130R + 127.38 \text{ (US \$/kVar)} \qquad (2)$$

SVC:

$$C_{SVC} = 0.0003R^2 - 0.2691R + 188.22 \text{ (US \$/kVar)} \qquad (3)$$

Here, R is the operating range of the FACTS Devices.

3. Optimal Location of Facts Devices

The decision where to place a FACTS device is largely depends on the desired effect and the characteristics of the specific system. Static VAr Compensators (SVC) is mostly suitable when Reactive Power flow or Voltage support is necessary. TCSC devices are not suitable in lines with high Reactive Power flow. Also, the cost of the devices plays an important role for the choice of a FACTS device. Having made the decision to install a FACTS device in the system, there are three main issues that are considered: type of device, capacity and location. There are two distinct means of placing a FACTS device in the system for the purpose of increasing the system's ability to transmit power, thereby allowing for the use of more economic generating units. That is why, FACTS devices are placed in the more heavy loaded lines to limit the power flow in that line. This causes more power sent through the remaining portions of the system while protecting the line with the device for being overloaded. This method which sites the devices in the heavy loaded line is the most effective. If Reactive Power flow is a significant portion of the total flow on the limiting transmission line, either a TCSC device in the line or A SVC device located at the end of the line receives the Reactive Power, may be used to reduce the Reactive Power flow, thereby increasing the Active Power flow capacity. Again, it is found that UPFC is the most powerful and versatile FACTS device due to the fact that line impedance, voltage magnitude and phase angle can be changed by the same device.

4. Proposed Approach

Here, the main objective is to minimize the transmission loss by incorporating FACTS device in suitable locations of the transmission network. Inclusion of FACTS controller also increases the system cost, so optimal placement of FACTS devices are required such the gain obtained by reducing the transmission loss must be significant even after the placement of costly FACTS devices. Here, cost functions of the different FACTS devices are considered and associated in the objective function. Without FACTS devices transmission loss can be minimized by optimization of reactive power which is possible by controlling reactive generation of the generators, controlling transformer tap settings, and by the addition of shunt capacitors at weak buses. But with FACTS devices, both the active and the reactive power flow pattern can be changed and significant system performance is noticed. The optimal allocation of FACTS devices can be formulated as:

CTOTAL=C1(E)+C2(F) (4)

Subject to the nodal active and reactive power balance

$$P_{ni}^{\min} \le P_{ni} \le P_{ni}^{\max} \tag{5}$$

$$Q_{ni}^{\min} \le Q_{ni} \le Q_{ni}^{\max} \tag{6}$$

And Voltage magnitude constraints: $V_i^{\min} \le V_i \le V_i^{\max}$ (7)

And the existing nodal reactive capacity constraints: $Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}$ (8)

Superscripts min, max= minimum and maximum limits of the variables. Here, C1(E) is the cost due to energy loss and C2(F) is the total investment cost of the FACTS devices. In this approach, first, the locations of FACTS devices are defined by calculating the power flow in each line. UPFC positions are determined by identifying the lines carrying large active power. The active power flow is very high in lines 6,7 & 4. These lines are connected between buses (2,6), (4,6) & (3,6) respectively. Here, the voltage magnitude and the phase angle of the 2nd,4th and the 3rd buses (those are at the starting end of the lines 6,7 & 4 respectively) are controlled. Then TCSC positions are selected by choosing the lines carrying large reactive power. Lines 41,25 &18 found as the lines for TCSC placement and simultaneously series reactance of these lines are controlled. Finally, 17th,7th & 21st bus is found as the buses where suitable reactive injection by SVC could improve the system performance. The function of the ACA is to find the optimum value of the different FACTS devices. Here, three different types of FACTS devices are used. And for each type of FACTS devices, three positions are assigned. Since one UPFC element controls magnitude and phase angle of a bus, three UPFC element controls six values, three for bus voltage magnitude & three for phase angle. Three TCSC modifies reactance of three lines. Similarly, three SVCs are control reactive injection at three buses. So, as a whole twelve values are to be optimized by Ant Colony Algorithm. These twelve controlling parameters are represented with in a string. This is shown in Figure 1. Initially, a population of N strings of ant is randomly created to node in such a way so that the parameter values should be with in their limits. Then the objective function is computed for every individual of the population. ACSA shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA).The system is initialized with a population of random solutions and searches for optimal by updating generations. However, unlike GA, ACSA has no evolution operators such ass crossover and mutation. ACSA is a relatively new meta heuristic for hard solving combinatorial optimization problems. This algorithm was proposed by Dorigo and colleagues [15]-[16] & [9]. It is population-based approach that uses exploitation of positive feedback, distributed computation as well as constructive greedy heuristic. Positive feedback is for fast discovery of good solutions, distributed computation avoids early convergence, and the greedy heuristic helps find adequate solutions in the early stage of the search process

4.1. Ant colony optimization:

The ACSA imitates the behaviors of real ants [8]. As it is well known, real ants are capable of finding the shortest path from food sources to the nest without using visual cues. Also, they are capable of adapting the changes of environment, for example, finding a new shortest path once the old one is no longer feasible due to a new obstruction. Moreover, the ants manage to establish shortest paths through the medium that is called “pheromone.” The pheromone is the material deposited by the ants, which serves as critical communication information among ants, thereby guiding the determination of the next movement. Any trail is rich of pheromone will thus become the goal path.

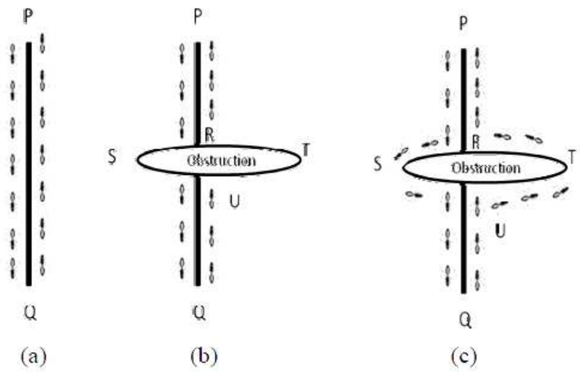


Figure 1. Example of the real ant’s behavior.

In Figure 1, the ants are moving from food source P to the nest Q on a straight line. Once an obstacle appears as shown in Figure 1(b), the path is cut off. The ants will not be able to follow the original trail on their movements. Under this situation, they have the same probability to turn right or left. But after some time, the path RS will have more pheromones and all the ants will move in the path PRS. As the ants from R to reach T through S, they will reach quicker than those ants through T, i.e., RTU. Hence, ant at U from Q will find pheromone a path USRP and will go through it, where figure 1(c) depicts that the shorter path RSU will collect larger amount of pheromone than the longer path RTU. Therefore, more ants will be increasely guided to move on the shorter path. Due to this autocatalytic process, soon all ants will choose the shorter path. This behavior forms the fundamental paradigm of the ant colony search algorithm.

Algorithm for congestion management using ACSA based OPF:

1) Generate the population of ants and the level of pheromone randomly.
2) For every ant compute the fitness using fitness function.
3) Find *best P* and *best Q* routes among the population.
4) Update the pheromone.
5) Check for convergence. If convergence is not met, go to step 2 and repeat the process. If the convergence is met display the results.

5. Test Results

The ACA based placement of FACTS devices is applied in IEEE 30 bus system. The power system is loaded reactive loading which is considered and according FACTS devices are placed in the different positions (which are already defined). The power system is loaded upto 200% limit of base reactive load and accordingly the system performance is observed with and without FACTS devices. Table 1 shows the active power flow pattern without FACTS devices in different lines. Table 2 shows the reactive power flow pattern without FACTS devices in different lines. In Table 3 & Table 4, the active and reactive power flow in different lines with FACTS devices is shown. The magnitude and phase angle of the bus voltages with & without FACTS devices for 200% of loading are shown in Table 5. Phase angles are given in radian. The locations, where different FACTS devices are placed, are shown in Table 6. A comparative study of the operating cost of the system with and without FACTS devices are shown in Table 7. It is observed from the Table 6 that SVC's are connected at the buses 21, 17&7, those are at the finishing end of the lines 27, 26 and 9 respectively.

Since these are the three lines carry highest, second highest and third highest reactive power respectively as found in Table 2, without FACTS devices. After connecting SVC's at these buses, voltage profile at these buses improved as seen in Tables 5, also reactive power flow reduces in the lines 27, 26 & 9. There is slight increase of reactive power flow in line 9, in case of base loading with FACTS devices. TCSC's are placed in the lines 18, 25 & 41, as these are the next three highest reactive power carriers as seen in Table 2. UPFC 's are connected in the buses 3,2,4, those are at the starting end of the lines 4,7 & 6 respectively as these lines carry high active powers. It is also to be noticed that no FACTS devices are connected in line 1 because of the fact between bus 1 and bus 2 though it carries very large active power.

Table 1. Active Power Flow in lines without FACTS devices

Lines	Lines Between	Active power flow for 100% Reactive Loading	Active power flow for 125% Reactive Loading	Active power flow for 130% Reactive Loading	Active power flow for 160% Reactive Loading	Active power flow for 175% Reactive Loading	Active power flow for 200% Reactive Loading
1	1-2	0.9055	0.9071	0.9074	0.9098	0.9112	0.9139
2	1-3	0.4800	0.4797	0.4797	0.4796	0.4797	0.4800
3	2-4	0.2912	0.2916	0.2917	0.2924	0.2928	0.2936
4	3-4	0.4465	0.4463	0.4462	0.4462	0.4462	0.4465
5	2-5	0.5805	0.5816	0.5818	0.5832	0.5840	0.5854
6	2-6	0.3782	0.3782	0.3782	0.3783	0.3785	0.3789
7	4-6	0.3926	0.3899	0.3894	0.3862	0.3846	0.3821
8	5-7	-0.1309	-0.1298	-0.1296	-0.1282	-0.1275	-0.1262
9	6-7	0.3632	0.3622	0.3620	0.3608	0.3602	0.3591
10	6-8	-0.0078	0.0075	0-0074	-0.0069	-0.0066	-0.0061
11	6-9	0.1512	0.1500	0.1497	0.1483	0.1477	0.1466
12	6-10	0.1142	0.1135	0.1134	0.1126	0.1122	0.1116
13	9-11	-0.1793	-0.1793	-0.1793	-0.1793	-0.1793	-0.1793
14	9-10	0.3259	0.3247	0.3245	0.3231	0.3225	0.3215
15	4-12	0.2687	0.2717	0.2724	0.2763	0.2784	0.2821
16	12-13	-0.1691	-0.1691	-0.1691	-0.1691	-0.1691	-0.1691
17	12-14	0.0768	0.0776	0.0778	0.0789	0.0794	0.0804
18	12-15	0.1750	0.1760	0.1763	0.1776	0.1784	0.1797
19	12-16	0.0672	0.0683	0.0685	0.0699	0.0706	0.0719
20	14-15	0.0141	0.0149	0.0150	0.0160	0.0165	0.0174
21	16-17	0.0318	0.0328	0.0330	0.0343	0.0349	0.0360
22	15-18	0.0566	0.0575	0.0577	0.0589	0.0594	0.0604
23	18-19	0.0243	0.0252	0.0253	0.0264	0.0270	0.0279
24	19-20	-0.0708	-0.0699	-0.0697	-0.0686	-0.0681	-0.0672
25	10-20	0.0939	0.0931	0.0929	0.0919	0.09140	0.0906
26	10-17	0.0585	0.0575	0.0573	0.0561	0.0555	0.0545
27	10-21	0.1607	0.1605	0.1605	0.1603	0.1603	0.1603
28	10-22	0.0780	0.0781	0.0781	0.0782	0.0783	0.0784
29	21-22	0.0154	-00158	-0.0158	-0.0163	-0.0165	-0.0168
30	15-23	0.0484	0.0491	0.0492	0.0501	0.0505	0.0513
31	22-24	0.0621	0.0617	0.0616	0.0611	0.0609	0.0605
32	23-24	0.0162	0.0168	0.0169	0.0177	0.0181	0.0187
33	24-25	-0.0092	-0.0091	-0.0090	-0.0089	-0.0088	-0.0086
34	25-26	0.0354	0.0355	0.0355	0.0357	0.0358	0.0359
35	25-27	-0.0446	-0.0446	-0.0446	-0.0446	-0.0446	-0.0447
36	28-27	0.1631	0.1633	0.1633	0.1636	0.1638	0.1642
37	27-29	0.0619	0.0619	0.0619	0.0620	0.0620	0.0621
38	27-30	0.0709	0.0710	0.0710	0.0711	0.0711	0.0713
39	29-30	0.0370	0.0370	.0.370	0.0370	0.0370	0.0371
40	8-28	0.0422	0.0425	0.0426	0.0430	0.0432	0.0436
41	6-28	0.1359	0.1358	0.1358	0.1358	0.1358	0.1359

Bus 1 is the slack bus and already a FACTS device regulates the voltage of the bus 2. Again, in any line or in a bus connected with the line, only one FACTS device can be placed. It is clearly observed that connecting UPFC's, active and reactive power flow pattern is nicely re-distributed. Though two UPFC'S are regulating the voltages of the Generator bus 2, the voltage magnitude did not change significantly, i.e the generation control at Generator buses are still in hand. The maximum voltage magnitude at bus 2 and bus with FACTS devices is 1.0404.

Table 2. Reactive Power Flow in Lines without Facts Devices

Lines	Lines Between	Active power flow for 100% Reactive Loading	Active power flow for 125% Reactive Loading	Active power flow for 130% Reactive Loading	Active power flow for 160% Reactive Loading	Active power flow for 175% Reactive Loading	Active power flow for 200% Reactive Loading
1	1-2	0.0150	0.0145	0.0144	0.0137	0.0133	0.0126
2	1-3	-0.0033	0.0059	0.0078	0.0191	0.0248	0.0345
3	2-4	-0.0582	-0.0474	-0.0452	-0.0318	-0.0250	-0.0136
4	3-4	-0.0277	-0.0216	-0.0203	-0.0128	-0.0090	-0.0025
5	2-5	0.0390	0.0389	0.0388	0.0387	0.0386	0.0384
6	2-6	-0.0510	-0.0412	-0.0392	-0.0272	-0.0211	-0.0107
7	4-6	0.0241	0.0203	0.0196	0.0149	0.0126	0.0086
8	5-7	0.0297	0.0496	0.0536	0.0777	0.0899	0.1105
9	6-7	0.0731	0.0808	0.0823	0.0914	0.0958	0.1032
10	6-8	0.0134	-0.0281	-0.0365	-0.0874	-0.1133	-0.1572
11	6-9	-0.1101	-0.0928	-0.0893	-0.0680	-0.0571	-0.0386
12	6-10	-0.0314	-0.0173	-0.01440	0.0031	0.0120	0.0270
13	9-11	-0.02252	-0.2498	-0.2547	-0.2847	-0.2998	-0.3254
14	9-10	0.0315	0.0744	0.0830	0.1353	0.1618	0.2064
15	4-12	-0.0685	-0.0514	-0.0480	-0.0271	-0.0164	0.0016
16	12-13	-0.3016	-0.3444	-0.3529	-0.4047	-0.4308	-0.4747
17	12-14	0.0198	0.0272	0.0287	0.0376	0.0421	0.0497
18	12-15	0.0507	0.0717	0.0760	0.1016	0.1146	0.1365
19	12-16	0.0168	0.297	0.0323	0.0479	0.0559	0.0692
20	14-15	0.0024	0.0056	0.0062	0.0102	0.0122	0.0155
21	16-17	-0.0020	0.0062	0.0078	0.0178	0.0228	0.0313
22	15-18	0.0091	0.0163	0.0177	0.0263	0.0307	0.0380
23	18-19	-0.0005	0.0043	0.0052	0.0110	0.0139	0.0188
24	19-20	-0.0346	-0.0383	-0.0391	-0.0435	-0.0457	-0.0493
25	10-20	0.0441	0.0497	0.0508	0.0575	0.0608	0.0664
26	10-17	0.0608	0.0671	0.0684	0.0760	0.798	0.0860
27	10-21	0.0939	0.1184	0.1233	0.1528	0.1677	0.1925
28	10-22	0.0419	0.0534	0.0557	0.0696	0.0766	0.0883
29	21-22	-0.0205	-0.0244	-0.0252	-0.0299	-0.0323	-0.0361
30	15-23	0.0149	0.0254	0.0275	0.0403	0.0467	0.0576
31	22-24	-0.0204	0.0277	0.0292	0.0381	0.0425	0.0500
32	23-24	-0.0016	0.0048	0.0061	0.0139	0.0178	0.0244
33	24-25	-0.0073	0.0114	-0.0122	-0.0171	-0.0195	-0.0235
34	25-26	0.0237	0.0295	0.0307	0.0378	0.0414	0.0474
35	25-27	-0.0310	-0.0410	-0.0430	-0.0551	-0.0611	-0.0712
36	28-27	-0.0383	-0.0207	-0.0171	0.0046	0.0156	0.0345
37	27-29	0.0166	0.0203	0.0210	0.0255	0.0277	0.0315
38	27-30	0.0166	0.0201	0.0208	0.0251	0.0273	0.0309
39	29-30	0.0060	0.0074	0.0077	0.0093	0.0101	0.0114
40	8-28	0.0083	0.0193	0.0215	0.0351	0.0421	0.0539
41	6-28	0.0421	0.0500	0.0516	0.0615	0.0665	0.0751

Table 3. Active Power Flow in lines with facts devices

Lines	Between Buses	Active power flow with FACTS in p.u for 100% Loading	Active power flow with FACTS in p.u for 125% Loading	Active power flow with FACTS in p.u. for 130% Loading	Active power flow with FACTS in p.u. for 160% Loading	Active power flow with FACTS in p.u. for 175% Loading	Active power flow with FACTS in p.u. for 200% Loading
1	1-2	0.9069	0.9078	0.9084	0.9090	0.9199	0.9221
2	1-3	0.4790	0.4787	0.4786	0.4791	0.4843	0.4789
3	2-4	0.2912	0.2914	0.2915	0.2915	0.2923	0.2923
4	3-4	0.4456	0.4453	0.4452	0.4457	0.4507	0.4455
5	2-5	0.5795	0.5802	0.5797	0.5794	0.5781	0.5807
6	2-6	0.3793	0.3796	0.3800	0.3811	0.3865	0.3811
7	4-6	0.3963	0.3961	0.3973	0.4021	0.4241	0.3975
8	5-7	0.1317	-0.1311	-0.1316	-0.1319	-0.1331	-0.1307
9	6-7	0.3641	0.3635	0.3639	0.3641	0.3656	0.3628
10	6-8	-0.0083	-0.0297	-0.0299	-0.0306	-0.0112	-0.0309
11	6-9	0.1548	0.1525	0.1537	0.1593	0.1841	0.1566
12	6-10	0.1162	0.1149	0.1156	0.1186	0.1321	0.1171
13	9-11	-0.1793	-0.1793	-0.1793	-0.1793	-0.1793	-0.1793
14	9-10	0.3294	0.3271	0.3284	0.3338	0.3579	0.3312
15	4-12	0.2642	0.2643	0.2631	0.2587	0.2417	0.2640
16	12-13	-0.1691	-0.1691	-0.1691	-0.1691	-.01691	-0.1691
17	12-14	0.0757	0.0760	0.0758	0.0749	0.0705	0.0764
18	12-15	0.1733	0.1727	0.1721	0.1704	0.1645	0.1722
19	12-16	0.0656	0.0661	0.0656	0.0639	0.0578	0.0659
20	14-15	0.0131	0.0133	0.0130	0.0122	0.0079	0.0135
21	16-17	0.0302	0.0307	0.0302	0.0286	0.0212	0.0305
22	15-18	0.0553	0.0560	0.0556	0.0543	0.0482	0.0560
23	18-19	0.0230	0.0237	0.0233	0.0220	0.0159	0.236
24	19-20	-0.0721	-0.0714	-0.0717	-0.0730	-0.0793	-0.0714
25	10-20	0.0953	0.0947	0.0951	0.0967	0.1040	0.0953
26	10-17	0.0601	0.0596	0.0601	0.0618	0.0710	0.0599
27	10-21	0.1626	0.1609	0.1616	0.1651	0.1798	0.1644
28	10-22	0.0789	0.0778	0.0782	0.0800	0.0875	0.0799
29	21-22	-0.0134	-0.0150	0.0143	-0.0108	0.0031	-0.0116
30	15-23	0.0471	0.0460	0.0456	0.0442	0.0405	0.0454
31	22-24	0.0650	0.0623	0.0634	0.0688	0.0895	0.0677
32	23-24	0.0149	0.0138	0.0134	0.0121	0.0083	0.0131
33	24-25	-0.0076	-0.0116	0.0110	-0.0076	0.0065	-0.0078
34	25-26	0.0354	0.0355	0.0355	0.0357	0.0357	0.0359
35	25-27	-0.0431	-0.0472	0.0465	-0.0453	-0.0296	-0.0437
36	28-27	0.1616	0.1655	0.1650	0.1620	0.1492	0.1628
37	27-29	0.0619	0.0619	0.0619	0.0619	0.0619	0.0621
38	27-30	0.0709	0.0709	0.0709	0.0710	0.0710	0.0712
39	29-30	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370
40	8-28	0.0416	0.0203	0.0200	0.0193	0.0383	0.0191
41	6-28	0.1349	0.1605	0.1602	0.1577	0.1247	0.1589

Table4. Reactive Power Flow in lines with facts devices

Lines	Between Buses	Reactive power flow with FACTS in p.u for 100% Loading	Reactive power flow with FACTS in p.u for 125% Loading	Reactive power flow with FACTS in p.u. for 130% Loading	Reactive power flow with FACTS in p.u. for 160% Loading	Reactive power flow with FACTS in p.u. for 175% Loading	Reactive power flow with FACTS in p.u. for 200% Loading
1	1-2	-0.0855	-0.0690	-0.2042	-0.0801	-0.0617	-0.0563
2	1-3	-0.0153	-0.0074	-0.0102	-0.0101	-0.0356	0.0055
3	2-4	-0.0402	-0.0338	-0.0292	-0.0345	-0.0731	-0.0206
4	3-4	-0.0396	-0.0346	-0.0380	-0.0415	-0.0696	-0.0308
5	2-5	0.0689	0.0662	0.0736	0.0694	0.0638	0.0651
6	2-6	-0.0304	-0.0258	-0.0214	-0.0301	-0.0734	-0.0192
7	4-6	0.0363	0.0291	0.0289	0.0137	-0.0097	0.0023
8	5-7	0.0190	0.0238	0.0130	-0.0078	-0.0808	0.0082
9	6-7	0.0838	0.0748	0.0670	0.0452	0.0170	0.0352
10	6-8	0.0655	0.0396	0.0551	0.0711	0.2168	0.0053
11	6-9	-0.1268	-0.1141	-0.1176	-0.1330	-0.2310	-0.1013
12	6-10	-0.0455	-0.0351	-0.0382	-0.0500	-0.1272	-0.0244
13	9-11	-0.1990	-0.2175	-0.2111	-0.1930	-0.0652	-0.2364
14	9-10	-0.0126	0.0195	0.0093	-0.0254	-0.2604	0.0517
15	4-12	-0.0737	-0.0590	-0.0584	-0.0567	-0.1037	-0.0269
16	12-13	0-2742	-0.3115	-0.3083	-0.3111	-0.1906	-0.3847
17	12-14	0.0167	0.0233	0.0234	0.0264	0.0134	0.0385
18	12-15	0.0381	0.0556	0.0546	0.0560	-0.0008	0.0913
19	12-16	0.0001	0.0098	0.0045	-0.0173	-0.1265	0.0088
20	14-15	-0.0007	0.0018	0.0012	-0.0007	-0.0157	0.0048
21	16-17	-0.0187	-0.0135	-0.0197	-0.0469	-0.1614	-0.0280
22	15-18	0.0020	0.0075	0.0058	0.0004	-0.0377	0.0130
23	18-19	-0.0076	-0.0045	-0.0065	-0.0146	-0.0541	-0.0057
24	19-20	0.0417	-0.0470	-0.0508	-0.0691	-0.1140	-0.0738
25	10-20	0.0513	0.0586	0.0629	0.0841	0.1323	0.0919
26	10-17	0.0570	0.0680	0.0642	0.0426	-0.0754	0.0686
27	10-21	0.0517	0.0623	0.0519	0.0131	-0.1643	0.0503
28	10-22	0.0259	0.0320	0.0286	0.0171	-0.0465	0.0344
29	21-22	0.0104	0.0158	0.0267	0.0753	0.2317	0.0681
30	15-23	0.0067	0.0147	0.0135	0.0111	-0.0258	0.0284
31	22-24	0.0354	0.0468	0.0543	0.0913	0.1829	0.1014
32	23-24	-0.0098	-0.0057	-0.0077	-0.0149	-0.0542	-0.0041
33	24-25	0.0001	-0.0020	0.0001	0.0090	0.0502	0.0009
34	25-26	0.0236	0.0295	0.0307	0.0378	0.0413	0.0473
35	25-27	-0.0235	-0.0315	-0.0306	-0.0288	0.0082	-0.0464
36	28-27	-0.0463	-0.0309	-0.0306	-0.0245	-0.0594	0.0058
37	27-29	0.0166	0.0203	0.0210	0.0245	0.0275	0.0313
38	27-30	0.0165	0.0201	0.0208	0.0250	0.0270	0.0308
39	29-30	0.0060	0.0074	0.0076	0.0092	0.0100	0.0114
40	8-28	-0.0019	0.0053	0.0024	-0.0000	-0.0289	0.0155
41	6-28	0.0420	0.0536	0.0590	0.0699	0.0778	0.0922

Table 5. Bus Voltages and Phase Angles with and without facts devices for 200% active & reactive loading

Bus No.	Bus Voltage without FACTS devices in p.u	Bus Voltage with FACTS devices in p.u		Bus Angle without FACTS devices in degree	Bus Angle with FACTS devices in degree	
		GA	ACA		GA	ACA
2	1.0338	1.0388	1.0338	-2.7635	-2.8291	-2.8290
5	1.0058	1.0058	1.0052	-9.0763	-8.9890	-8.820
8	1.023	1.023	1.023	-6.5343	-6.4411	-6.4411
11	1.0883	1.0883	1.0883	-6.1855	-6.3613	-6.3613
13	1.0913	1.0913	1.0913	-12.6761	-8.0117	-7.0122
30	0.9570	0.9785	0.9805	-10.1753	-12.2179	-12.2179
17	0.9941	1.0313	1.0343	-7.9513	-10.3176	-10.4176
7	0.9990	1.0110	1.0223	-10.3791	-8.1132	-8.1090
21	0.9832	1.0297	1.0345	-8.6790	-10.7316	-10.7231

Table 6. Locations of Different facts devices in the transmission network

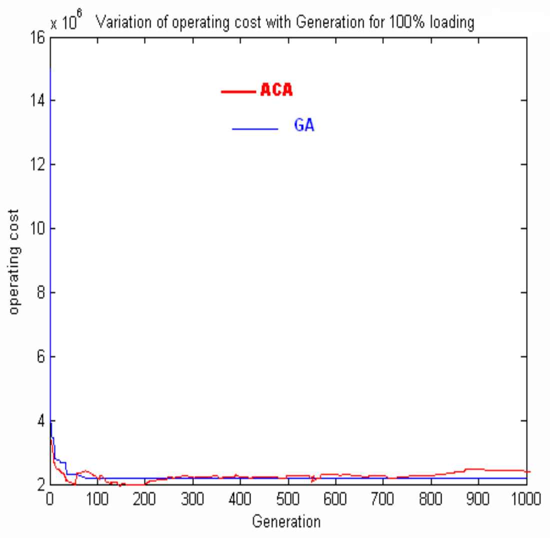
UPFC in Lines & Between Lines	TCSC in Lines & Between Lines	SVC Connected in Bus
Line 6 (2-6)	Line 14 (6-28)	17
Line 7(4-6)	Line 25 (10-20)	7
Line 4(3-4)	Line 18 (12-15)	21

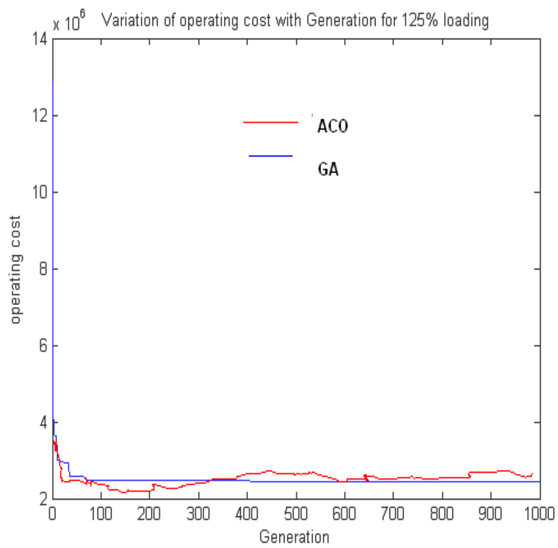
Table 7. Comparative Study with and without facts devices

Reactive loading	Active power Loss Without FACTS Devices	Active power Loss With FACTS Devices		Operating Cost without FACTS Devices Cost Due to energy lost FACT devices) in $	Operating Cost with FACTS Devices Cost Due to energy lost and FACT devices) in $		Cost of FACTS Devices		Net savings In $	
		GA	ACO		GA	ACO	GA	ACO	GA	ACO
100%	0.071	0.0410	0.0390	3.737016×10^6	2.1655×10^6	2.1400×10^6	10540	10360	1571516	1541316
125%	0.0724	0.0462	0.0400	3.8053×10^6	2.4527×10^6	2.4000×10^6	24428	23367	1352600	1294500
130%	0.0727	0.0486	0.0440	3.821112×10^6	2.5874×10^6	2.3458×10^6	32984	31902	1233712	1233015
160%	0.0750	0.0494	0.0467	3.94200×10^6	2.6537×10^6	2.1545×10^6	57236	56789	1288300	124560
175%	0.0765	0.0584	0.0523	4.020840×10^6	3.1849×10^6	2.9014×10^6	115396	11435	835940	829701
200%	0.0795	0.0665	0.0590	4.178520×10^6	3.5564×10^6	3.3990×10^6	61200	57234	622120	614567

From Table 7, we observe that transmission loss reduced significantly with FACTS devices as compared without FACTS Devices. A significant economic gain is achieved even at a loading of 200% of base reactive loading. Energy cost is taken as 0.06$/kWh by using Genetic Algorithm and 0.0590$/KWh by Ant Colony Algorithm, similarly various parameters are optimization using ACA methods. Figure 1 shows the different FACTS devices to be installed in the system with in a string. Figure 2 to Figure 7 show the variation of operating cost with generation for different cases of reactive loading of the system.

6. Simulation Results





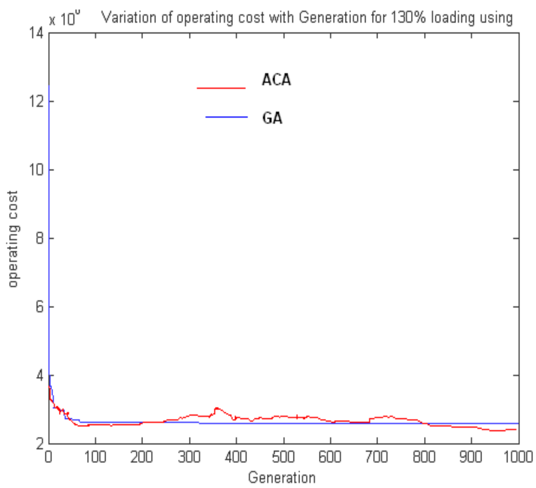


Figure 4. Variation of Total Cost with Generation for 130% Reactive loading

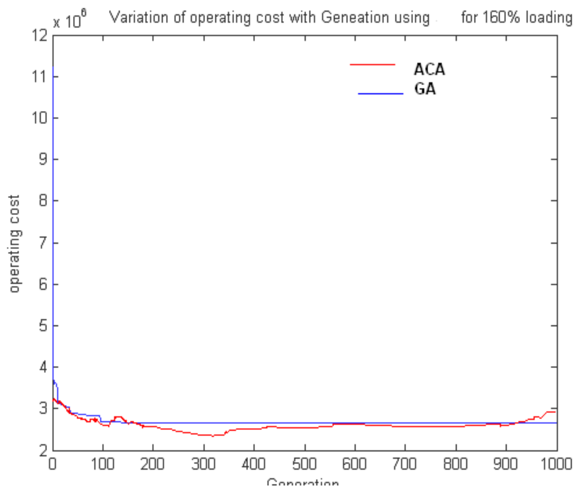


Figure 5. Variation of Total Cost with Generation for 160 % Reactive loading

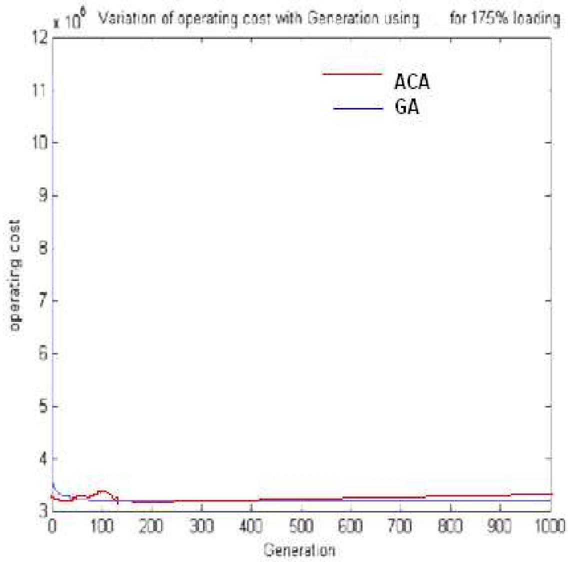


Figure 6. Variation of Total Cost with Generation for 175 % Reactive loading

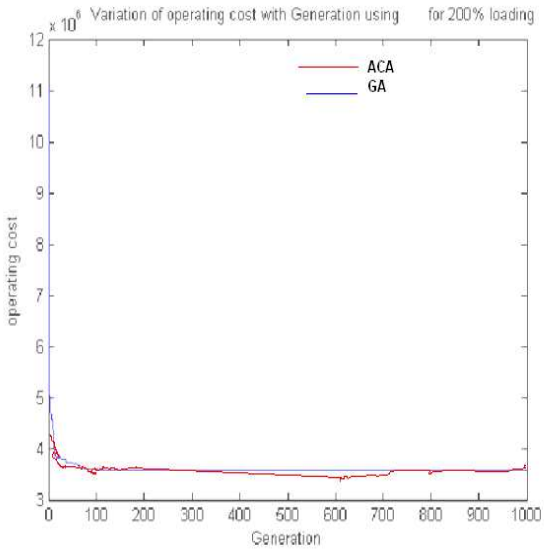


Figure 7. Variation of Total Cost with Generation for 200 % Reactive loading

7. Conclusion

In this approach, ACA based optimal placement of FACTS devices in a transmission network is done for the increase loadability of the power system as well as to minimize the transmission loss. Three different types of FACTS devices have considered. It is clearly evident from the results that effective placement of FACTS devices in proper locations can significantly improve system performance. This approach could be a new technique for the installation of FACTS devices in the transmission system.

Rreferences

[1] N Hingorani. Flexible AC Transmission. *IEEE Spectrum*.1993; 30(4): 40-45.
[2] M Noroozian, G Anderson. Power Flow Control by use of controllable Series Components. *IEEE Trans. Power Delivery*. July 1993; 8(3): 1420-1429
[3] M Iravani, et al. Application of static Phase Shifters in Power Systems. *IEEE Trans Power Delivery.* July 1994; 9(3): 1600-1608.
[4] D Ramey, R Nelson, J Bian, T Lemak. *Use of FACTS Power Flow Controllers to enhance Transmission Transfer Limits.* Proceedings American Power Conference. April 1994; 56(1): 712-718.
[5] R Nelson, J Bian, S Williams. Transmission Series Power Flow Control. *IEEE Trans. Power* delivery. January 1995; 10(1): 504-510.
[6] D J Gotham, G T Heydt. Power Flow Control and Power Flow Studies for System with FACTS Devices. *IEEE Trans Power System.* February 1998; 13(1).
[7] F D Galiana, K Almeida. Assessment and Control of The Impact Of FACTS Devices On Power System Performance. IEEE Transactions on Power Systems. November 1996; 11(4): 1931-1936.
[8] T T Lie, W Deng. Optimal Flexible AC Transmission Systems (FACTS) devices allocation. Electrical Power & Energy System. 1997; 19(2): 125-134.
[9] T S Chung, Y Z Li. A Hybrid GA approach for OPF with Consideration of FACTS Devices. *IEEE Power Engineering Review*. February 2001: 47-57.
[10] S N Singh, A K David. Optimal location of FACTS devices for congestion management. Electric Power System Research. 2001; 58: 71-79.
[11] K S Verma, S N Singh, H.O.Gupta. Location of Unified Power Flow Controller for Congestion Management. Electric Power Systems Research. 2001; 58: 89-96.
[12] S Gerbex, R Cherkaoui, A J Germond. Optimal Location of Multitype FACTS Devices in a Power System by Genetic Algorithm. *IEEE Trans. Power System.* August 2001; 16: 537-544,
[13] Harry Singh, Shan You, Alex Papalexopalos. Transmission congestion management in competitive electricity market. IEEE Transactions on Power Systems. May 1998; 13(2): 672-680.

[14] P W Sauer, K D Demaree, M A Pai. Stability limited load supply and interchange capability. *IEEE Trans. Power Apparat. Syst*. November 1983; 102: 3637–3643.
[15] V Vittal, E Z Zhou, C Hwang, A A Fouad. Derivation of stability limits using analytical sensitivity of the transient energy margin. *IEEE Trans. Power Syst*. Nov 1989; 4: 1363–1372.
[16] J Sterling, M A Pai, P W Sauer. A method of secure and optimal operation of a power system for dynamic contingencies. Electric Machine and Power Systems.1991; 19: 639–655.
[17] L L Lai, J T Ma, R Yokoyama, M Zhao. Improved genetic algorithms for optimal power flow under both normal and contingent operation states. Elec. Power Energy Syst. 1997; 19(5): 287–292.
[18] Dorigo M, Maniezzo V, and Colorni A. Ant System: "Optimization by a colony of cooperating agents ". *IEEE Trans. Syst.* Man, and Cybern. Part B. 1996; 26(1): 29.
[19] E Handschin, C Lehmkoester. *Optimal power flow for deregulated systems with facts-devices*. In Proc. 13th Power Syst. Comput. Conf.Trondheim, Norway. June 28–July 2, 1999: 1270–1276.
[20] Kalyan K Sen. SSSC - Static Synchronous Series Compensator: Theory, Modeling, and Applications. IEEE Transactions on Power Delivery. January 1998; 13(1): 241-246.
[21] Xing –Ping Zhang. Advanced Modeling of the Multicontrol Functional Static Synchronous Series Compensator (SSSC) in Newton Power Flow. *IEEE Transactions on Power Systems*. Nov 2003; 18(4).
[22] Muwaffaq I Alomoush. Static Synchronous Series Compensator to Help Energy Markets Resolve Congestion-Caused Problems. IEEE. 2004: 25-29.
[23] S N Singh, A K David. Congestion Management by Optimizing FACTS Device Location. IEEE. April, 2000: 23-28.
[24] Dorigo M. Optimization, Learning and Natural Algorithms. Ph.D. thesis. Italia: Dipartimento di Elettronica, Politecnico, di Milano: 1992.
[25] Shi Libao, Hao Jin, Zhou Jiaqi, Xu Guoyu. Ant colony optimization algorithm with random perturbation behaviour to the problem of optimal unit commitment with probabilistic spinning reserve determination. Electric Power Syst Res. 2004; 69: 295–303.