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OPTIMAL Placement of FACTS Devices by Genetic Algorithm for the Increased Load Ability of a Power System

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***Abstract*—**This paper presents Genetic Algorithm (GA) 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 GA based approach is applied on IEEE 30 BUS System. The system is reactively loaded starting from base to 200% of base load. FACTS devices are installed in the different locations of the power system and 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. Genetic Algorithm is then applied to find the amount of magnitudes of the FACTS devices. This approach of GA 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, Genetic Algorithm.

I. INTRODUCTION

RECENTLY FACTS technology have 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 of FACTS devices, flexible power flow control is possible. It is known that the power flow through an ac transmission line is 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 increased use of transmission capacity by FACTS devices are discussed in [1]. A scheme of power flow control in lines is discussed in [2]. 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] author's have discussed about the power flow control in transmission network. About the modeling and selection of possible locations for the installation of FACTS devices have been discussed in [6]. 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. Allocation of variable series capacitor & static phase shifters in transmission lines was the main objective in [8] for the optimal power flow. A hybrid Genetic Algorithmic approach with FACTS devices for optimal power flow is dealt in [9].

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In a congested power system, first the locations of the FACTS devices were decided based on the sensitivity factors and then 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 increased power flow. The objective of this present work is the optimal allocation of FACTS devices in the transmission network so the transmission loss becomes minimized 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, 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 the other lines where major reactive power flows take place. A Genetic Algorithm based approach considering the simultaneous effect of of the three types of the FACTS devises are presented and the effectiveness of this technique is clearly evident from the result shown.

II. FACTS DEVICES

A. *Modelling of FACTS Devices*

Mathematical modeling of FACTS devices are 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 $0.1V_{max}$, where V_{max} is the maximum voltage of the transmission line. The working range of the UPFC angle is between -180 degree to +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 X_L and $0.2X_L$ is the maximum value of the inductance, where X_L 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 ; a capacitive and one inductive. So function of the SVC is either to inject reactive power to bus or to absorb reactive power from the bus where it is connected.

B. FACTS Devices Cost Functions

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

UPFC:

$c_{UPFC} = 0.0003R^2 - 0.2691R + 188.22$ (US $/kVar)

TCSC:

c_{TCSC}=0.0015R2-0.7130R+127.38 (US $/kVar)

SVC:

$c_{SVC} = 0.0003R^2 - 0.2691R + 188.22$ (US $/kVar)

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

III. Optimal Siting of FACTS Devices

The decision where to place a FACTS device is largely dependent on the desired effect and the characteristics of the specific system. Static VAr Compensators (SVC) are 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 costs of the devices play 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 to be 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 heavily loaded lines to limit the power flow in that line. This causes more power to be 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 heavily 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 that 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 the fact that line impedance, voltage magnitude and phase angle can be changed by the same device.

IV. The Proposed Approach

Here the main objective is to minimize the transmission loss by incorporating FACTS devices in suitable locations of the transmission network. Inclusion of FACTS controller also increase system cost So optimal placement of FACTS devices are required such that 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 generations of the Generator's, controlling transformer tap settings, and by the addition of shunt capacitors at weak buses. But with FACTS devices both the active and reactive power flow pattern can be changed and significant system performance is noticed. The optimal allocation of FACTS Devices can be formulated as:

C_{TOTAL}=C1(E)+C2(F)

Subject to the nodal active and reactive power balance

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

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

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

And the existing nodal reactive capacity constraints:

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}$$

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 at 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 again 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 GA 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. Again 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 SVC's are to control reactive injection at three buses. So, as a whole twelve values are to be optimized by Genetic Algorithm. These twelve controlling parameters are represented with in a string. This is shown in Fig 1. Initially a population of N strings are randomly created 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. A biased roulette wheel is created from the values obtained after computing the objective function for all the individuals of the current population. Thereafter the usual Genetic operation such as Reproduction, Cross-over & Mutation takes place. Two individual are randomly selected from the current population for reproduction. Then Cross-over takes place with a probability close to one (here 0.8). Finally mutation with a specific probability (very low) completes one Genetic cycle and individuals of same population with improved characters are created in the next generation. The objective function is then again calculated for all the individual of the new generation and all the genetic operations are again performed and the second generation of same population size is produced. This procedure is repeated till the final goal is achieved.

V. Test Results

The GA based placement of FACTS devices is applied in IEEE 30 Bus system. The power system is loaded (reactive loading is considered) and accordingly FACTS devices are placed in the different positions (which are already defined). The power system is loaded upto the limit of 200% 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 for are 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 is 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 that 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 from Table 2, without FACTS devices. After connecting SVC's at theses buses, voltage profile at these buses improved as seen from 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 carrier as seen from 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 that it is in between bus 1 and bus 2 though it carries very large active power. 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, but it's 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 I ACTIVE POWER FLOW IN LINES WITHOUT FACTS DEVICES

Lines	Lines between Buses	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	0.0914	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	-0.0158	-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	0.0370	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

From Table7, we observe that transmission loss reduced significantly with FACTS devices as compared to 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.

Fig 1. shows the different FACTS devices to be installed in the system with in a string. Fig 2 to Fig 7 shows the variation of operating cost with Generation for different cases of reactive loading of the system.

TABLE II REACTIVE POWER FLOW IN LINES WITHOUT FACTS DEVICES

Lines	Between Buses	Reactive power flow for 100% Reactive loading	Reactive power flow for 125% Reactive loading	Reactive power flow for130% Reactive loading	Reactive power flow for 160% Reactive loading	Reactive power flow for 175% Reactive loading	Reactive 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	-0.0144	0.0031	0.0120	0.0270
13	9-11	-0.2252	-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	0.0297	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	0.0798	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 III 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	0.9059	0.9069	0.9072	0.9079	0.9129	0.9100
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	-0.1691	-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	0.0236
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	-0.0433	-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

TABLE IV 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	-0.0877	-0.0790	-0.1042	-0.0901	-0.0717	-0.0763
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	0.0254	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	0.0440	0.0526	0.0559	0.0651	0.0578	0.0822

TABLE V 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
2	1.0338	1.0388	-2.7635	-2.8281
5	1.0058	1.0058	-9.0763	-8.9890
8	1.023	1.023	-6.5343	-6.4411
11	1.0883	1.0883	-6.1855	-6.3613
13	1.0913	1.0913	-8.2723	-8.0117
30	0.9570	0.9785	-12.6761	-12.2179
17	0.9941	1.0313	-10.1753	-10.3176
7	0.9990	1.0110	-7.9513	-8.1132
21	0.9832	1.0297	-10.3791	-10.7316

TABLE VI LOCATIONS OF DIFFERENT FACTS DEVICES IN THE TRANSMISSION NETWORK

UPFC in Lines & Between buses	TCSC in Lines & between Buses	SVC connected in the Buses
Line 6(2-6), Line 7(4-6), Line 4(3-4).	Line 41(6-28), Line 25(10-20), Line 18(12-15),	17, 7, 21

TABLE VII COMPARATIVE STUDY WITH AND WITHOUT FACTS DEVICES

Reactive Loading	Active power loss without FACTS Devices	Active power loss with FACTS Devices	Operating cost with out FACTS Devices (cost due to energy loss) in $	Operating cost with FACTS Devices (cost due to energy loss+ FACTS Devices) in $	Cost of FACTS Devices	Net savings in $
100%	0.0711	0.0410	3.737016×10^6	2.1655×10^6	10540	1571516
125%	0.0724	0.0462	3.8053×10^6	2.4527×10^6	24428	1352600
130%	0.0727	0.0486	3.821112×10^6	2.5874×10^6	32984	1233712
160%	0.0750	0.0494	3.94200×10^6	2.6537×10^6	57236	1288300
175%	0.0765	0.0584	4.020840×10^6	3.1849×10^6	115396	835940
200%	0.0795	0.0665	4.178520×10^6	3.5564×10^6	61200	622120

V_{UPFC1}	V_{UPFC2}	V_{UPFC3}	V_{ANG1}	V_{ANG2}	V_{ANG3}	X_1	X_2	X_3	SVC_1	SVC_2	SVC_3

Fig. 1 Genetic String Representing Control Variables

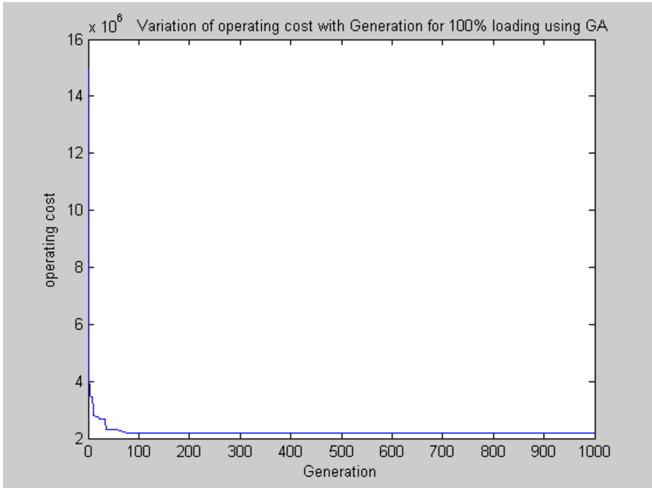

Fig. 2 Variation of Total Cost with Generation for 100% Reactive loading

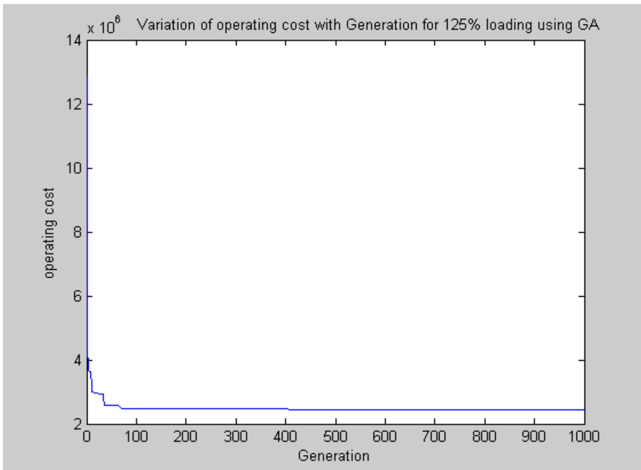

Fig. 3 Variation of Total Cost with Generation for 125% Reactive loading

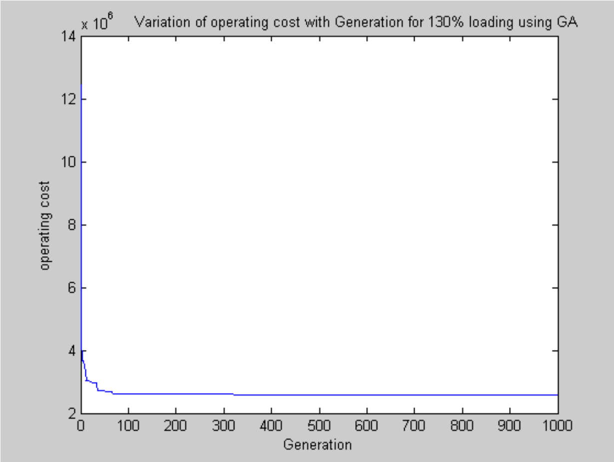

Fig. 4 Variation of Total Cost with Generation for 130% Reactive loading

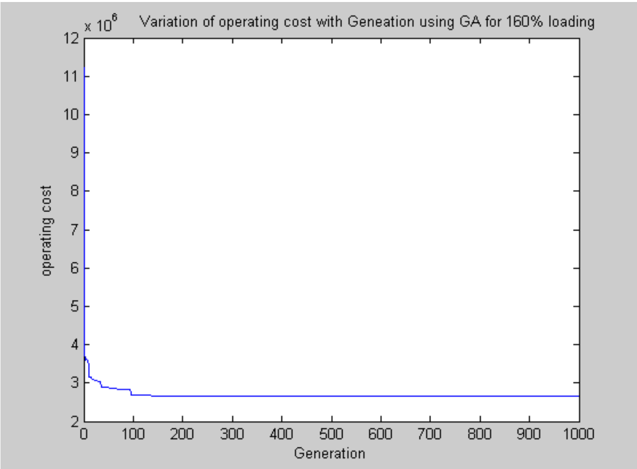

Fig .5 Variation of Total Cost with Generation for 160 % Reactive loading

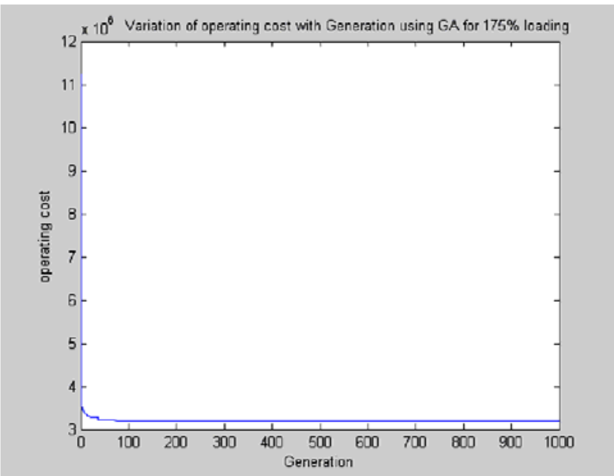

Fig. 6 Variation of Total Cost with Generation for 175 % Reactive loading

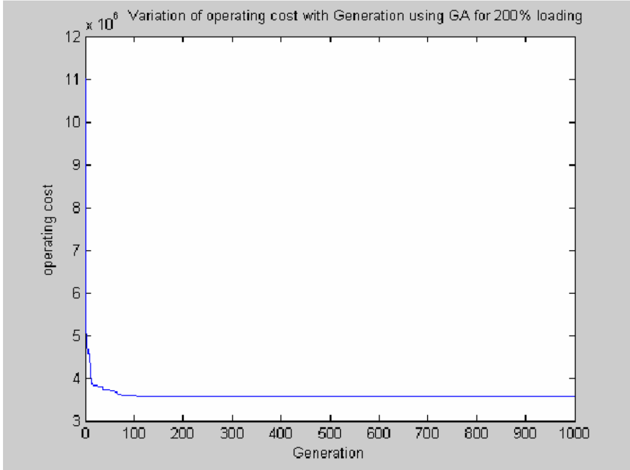

Fig. 7 Variation of Total Cost with Generation for 200 % Reactive loading

VI. Conclusion

In this approach, GA based optimal placement of FACTS devices in a transmission network is done for the increased loadability of the power system as well as to minimize the transmission loss. Three different type 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.

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