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Reducing Generation Cost in Transmission System using Facts Devices

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Reducing Generation Cost in Transmission System using Facts Devices

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Keywords: optimal power flow, genetic algorithm, SVC, TCSC, UPFC and LDC.

I. Introduction

Stringent requirements imposed on electric utilities in addition the environmental impact of constructing new transmission lines exert increasing restrictions on the expansion of existing transmission networks.

FACTS technology has introduced new, yet effective, ways of controlling a power network, which makes the system operation more flexible and secure. This is accomplished by targeting/ modifying key elements in power flow, namely transmission line impedance, phase angle, and voltage magnitude. The flexibility gained in this regard is an achievement not to be taken lightly as it benefits the power system economically and technically.

The flexibility to the power system offered by installing FACTS devices comes at substantial cost though and such necessitates careful planning of new installations of FACTS devices. One of the main elements of planning is the selection and placement of candidate FACTS devices in the power system which will provide the highest added value to the system in terms of cost saving and system operation improvements.

Various assessment tools exist, and have been used in the past for this purpose but the Optimal Power Flow (OPF) seems to be one of the best suited for this task due to its scalar measurability of the economic and technical benefits that play a crucial role in the investment decision. Some studies such as [1-2] used OPF for the allocation of FACTS devices in order to maximize the benefits arising from their usage while others [3-4], incorporated the FACTS devices cost in order to show them as a cost effective solution.

This paper focuses on economical benefits due to the installation of FACTS devices where the emphasis is on attaining maximum profitability over the lifetime of the devices. The allocation process relies heavily on OPF calculations and Genetic Algorithm (GA) optimizations for the placement of three types of FACTS devices (SVC, TCSC and UPFC) where the objective is founded on the cost of generated active power, net annual savings, and load growth. The annual Load Duration Curve (LDC) is employed in this study for the purpose of selecting a range of operating conditions and in turn having an unbiased solution.

II. Modelling of Facts Devices

From an operational point of view, the power flow in an electrical network between any two buses is governed by the voltage magnitudes and angles of the respective buses and impedance of the line is expressed as

$$P_{12} = \frac{v_1 v_2}{x} \sin(\delta_1 - \delta_2) \ldots\ldots\ldots \quad (1)$$

From this expression the FACTS devices of SVC, TCSC and UPFC are discussed in the following way.

a) Static Var Compensator (SVC)

Increasing power transfer during steady state conditions and controlling the voltage profile has long been recognized as key contribution of reactive shunt compensators. The reactive compensation changes the transmission line characteristics to cope with the load demand. A detailed review of Static Var Compensators can be found in [3, 7]. The steady state SVC model comprises two ideally switched parallel elements a

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variable capacitor and a variable inductor shown in Fig.1 the range of injected or absorbed values are lies between -80 MVAr to +80 MVAr. The mathematical model of SVC is described as [11]

$$I_{SVC} = jB_{SVC}V \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

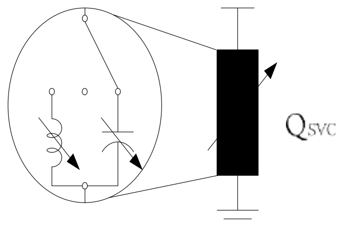

Fig.1 : SVC Steady State Model

From the fig.1 the reactive power is exchange with an 'i[th]' bus can be expressed as

$$Q^{i}_{SVC} = B^{i}_{SVC}.V_i^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where

i=1, 2, 3..........are the buses.

b) Thyristor Controlled Series Capacitor (TCSC)

A TCSC model in steady state which accounts for the compensation or gain in transmission line reactance consist of three ideally switched parallel elements such as a capacitor, an inductor, and a wire which is shown in fig.2. With this arrangement there is no effect of system performance. However the inductance and capacitance are variable and their values are expressed as a function of the line reactance.

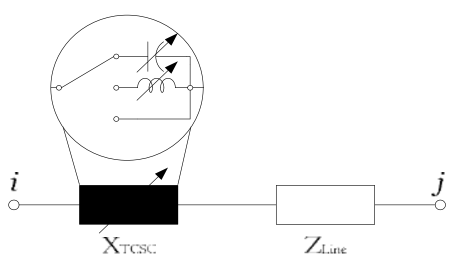

Fig. 2 : TCSC Steady State Model

The effective impedance of the transmission line with TCSC is governed by the following expression

$$\left.\begin{aligned} X_{eff} &= X_{line} + X_{TCSC} \\ &= (1+K)X_{line} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (4)$$

where

X_{line} and X_{TCSC} are the line and TCSC impedances, k is the degree of compensation[3, 7] which is obtained by

$$K = \frac{X_{TCSC}}{X_{line}} \qquad 0 \le K < 1$$

By considering the reference values in this study, the maximum value of gain was set at 20% of the line impedance while the maximum compensation was fixed at 80% of the line impedance.

c) Unified Power Flow Controller (UPFC)

Among the available FACTS devices, the UPFC is capable of supplying and absorbing both real and reactive power. The basic configuration of a UPFC is shown in Fig.3. And it consists of two ac/dc converters.

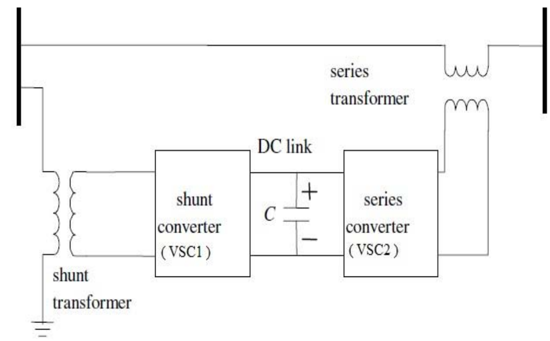

Fig. 3 : UPFC Steady State Model

One of the two converters is connected in series with the transmission line through a series transformer and the other in parallel with the line through a shunt transformer. The dc side of the two converters is connected through a common capacitor, which provides dc voltage for the converter operation. The power balance between the series and shunt converters is a prerequisite to maintain a constant voltage across the dc capacitor. As the series branch of the UPFC injects a voltage of variable magnitude and phase angle, it can exchange real power with the transmission line and thus improves the power flow capability of the line as well as its transient stability limit. The shunt converter exchanges a current of controllable magnitude and power factor angle with the power system. It is normally controlled to balance the real power absorbed from or injected into the power system by the series converter plus the losses by regulating the dc bus voltage at a desired value.

From the modelling analysis of FACTS devices the cost function of generation is evaluated with proposed FACTS devices which are described in the following subsequent sections in this paper.

III. GENERATION COST FUNCTIONS

The cost function of generated active power can be represented by a second order polynomial equation is

$$C_p = C_0 + C_1P + C_2P^2 \quad (\$/hr) \qquad \ldots\ldots\ldots (5)$$

The adopted values for the coefficients are taken from MATPOWER toolbox is shown in Table. 1. Where the first column represents the generator number, the second column shows the bus at which the generator is connected, and the rest of the columns represent the coefficient values accordingly.

Table 1 : Cost function coefficients

G_{num}	Bus	C_0	C_1	C_2
1	1	0	20	0.0775795
2	2	0	40	0.01
3	3	0	20	0.25
4	6	0	40	0.01
5	8	0	20	0.0222222
6	9	0	40	0.01
7	12	0	20	0.0322581

From the table.1cost function coefficient values are considered for evaluation of generation cost in transmission system.

IV. The Proposed Methodology

The aim of placement of the chosen FACTS devices in the network is to maximize the profits gained by such placement. The profit is created by reducing the generation cost (while at the same time obeying the limits imposed by the physical network, i.e., the thermal limits of the lines and the voltage limits of the buses) which introduces savings that will be compounded over the lifetime of the devices. On its own, the optimization problem is formulated based on the OPF variables which consist of real and reactive generator injections (Pg and Qg), and voltage magnitudes (V) and angles (θ) at each bus. Thus, the optimization problem is expressed as

$$min \sum_{n}^{N_p} (C_{pn}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Subject to

-Power balance equations for equality constraints are

$$\sum_{m}^{N_b} |V_j|\,|V_m|\left(G_{jm}\cos\theta_{jm} + B_{jm}\sin\theta_{jm}\right) - P_{gj} + P_{gj} = 0 \quad \ldots (7)$$

$$\sum_{m}^{N_b} |V_j|\,|V_m|\left(G_{jm}\sin\theta_{jm} - B_{jm}\cos\theta_{jm}\right) - Q_{gj} + Q_{gj} = 0 \quad \ldots (8)$$

-Operational Constraint

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

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

$$|V_j^{min}| \le |V_j| \le |V_j^{max}|$$

$$|S_j(\theta, V)| \le S_j^{max}$$

Where

N_b= Number of buses

N_g= Number of generator buses

N_T= Number of transmission lines

P_d= Power demand

S_j^{max}= Thermal limit

$G_{jm}+iB_{jm}$= jm[th] element of the Y-bus matrix

From the above analysis the FACTS devices are located in electrical transmission system with GA technique [12]. This is most versatile technology to identify the location of FACTS devices in the system with respect to OPF analysis. From the literature the annual load duration curve and corresponding operating conditions and their cumulative percentages are considered for the operation of FACTS devices in the system.

With this technique the following steps are summarised for the placement of FACTS devices in IEEE-57 bus system.

1. The Optimal Power Flow will run after each gradual increase in the network loading factor until the solution diverges. This divergence was a result of one or multiple network constraints violations. The load factor at the point of divergence is recorded as the limiting network loading factor.
2. Identify the areas at which load growth might occur and repeat step 1 but only for those buses that foresee load growth. The maximum loading factor is recorded in the same manner as of step1. This loading factor will be greater than that of the pervious step.
3. Based on a typical load duration curve eleven operating conditions are elected for use in the allocation of FACTS devices. The operating conditions will start at 100% of the system maximum demand coming down to the minimum one. The limiting network load is set as the maximum demand.
4. A total of three FACTS devices, i.e., one devices of each kind, are made available for the placement.
5. Genetic Algorithm originally discussed in [13] is modified i.e., made more computationally efficient and applied for the optimal placement of the FACTS devices.

Each device has two extra variables that need determination, rating and location. The SVCs have 50 buses available as possible locations, excluding the seven generator buses, and their allowed rating is from -80 MVAr to +80 MVAr.

On the other hand, the remaining FACTS devices have no restrictions at all as to where their allocation takes place. Finally, TCSC has a range of -0.8 to 0.2 of the line reactance and for UPFC has a range of 0.1 of max voltage and range of the angle between-180 degree to +180 degree

6. Only one device can be installed on a bus or a branch. Most practices call for a use of a penalty factor that increases the cost of allocation in case a second device is occupying the same location. This has the effect of eliminating the solution from further consideration. In this study the penalty factors were not applied, instead suggested locations of all devices are checked to insure that each device

occupies a distinct bus or branch otherwise the hypothesized locations are discarded.

From the proposed technique the IEEE-57 bus system is tested and the test results are described in the following section.

VII. Test of IEEE-57 Bus System

The layout of IEEE-57 bus system consists of 7 generator buses, 17 transformers and 80 transmission lines and the total load of P=1250.80MW and Q=336.40MVAR. For obtaining generation cost the system has tested with OPF-GA on MATPOWER tool box and the corresponding test results of generation cost, loading factors, annual savings and voltage profile are shown from table.2 to table.5.

Table 2 : Generating Cost

Parameter	Generating Cost			
	Without FACTS	With SVC	With TCSC	With UPFC
P_{G1}(MW)	142.63	141.29	141.07	140.28
P_{G2}(MW)	87.82	79.57	77.78	73.60
P_{G3}(MW)	45.07	44.64	44.45	44.37
P_{G6}(MW)	72.90	65.11	58.64	60.04
P_{G8}(MW)	459.83	454.49	450.44	451.00
P_{G9}(MW)	97.51	84.88	83.15	77.64
P_{G12}(MW)	361.54	356.71	357.73	352.84
Cost($/hr)	41737.7 0	38362.94	37836.71	37291.41
loss(MW)	16.513	15.103	15.717	14.886

From Table.2 it is observed that the generating cost is reduced with FACTS compared to base case and it is evident that the generating cost is reduced from 41737.70($/hr) to 38362.94($/hr), 37836.31($/hr), 37291.41($/hr) with SVC, TCSC, UPFC respectively. The corresponding power loss is also reduced from 16.513(MW) to 15.103(MW), 15.717(MW), 14.886(MW) respectively. From Table.2 it is also evident that the power produced by individual generating units also reduced with FACTS devices which intern reduces the total operating cost of the system.

The loading factors and load growth loading factors with respect to operating conditions are given in Table 3.

Table 3 : Loading Factors

Operating Condition number	Base case Loading Factor	Load growth Loading Factor	Yearly Operating Hours
1	1.0819	1.5060	87.9
2	0.8771	1.2209	788.4
3	0.8279	1.1524	876.0
4	0.7831	1.0900	876.0
5	0.7438	1.0353	876.0
6	0.7128	0.9923	876.0
7	0.6798	0.9463	876.0
8	0.6399	0.8908	876.0
9	0.5915	0.8233	876.0
10	0.5254	0.7313	876.0
11	0.3895	0.5422	876.0

From Table.3 the annual savings at different operating conditions and net annual saving are obtained which are given in Table.4

Table 4 : Annual Savings

Operating Condition number	with SVC ($)	with TCSC ($)	with UPFC ($)
1	229585.77	241669.23	290003.07
2	714.52	752.13	902.56
3	632.47	665.76	798.91
4	505.97	532.60	639.12
5	412.77	434.49	521.39
6	339.53	357.40	428.88
7	270.46	284.70	341.64
8	204.72	215.49	258.59
9	138.97	146.29	175.55
10	73.233	77.08	92.505
11	0	0	0
Net savings	232878.41	245135.17	294153.21

Table.4 shows the savings at different operating conditions and it is observed that the annual savings are 232878.41($), 245135.17($), 294153.21($) with SVC, TCSC, UPFC respectively.

In addition to the generating cost the voltage profile of the system also controlled/improved with FACTS devices which are shown in Table.5

Table 6 : Voltage profile

BUS No:	Voltage magnitude(p.u)			
	Base	SVC	TCSC	UPFC
1	1.009	1.007	1.008	1.006
2	1.008	1.005	1.006	1.004
3	1.003	1.001	1.003	1.001
4	1.006	1.004	1.008	1.004
5	1.016	1.013	1.017	1.013
6	1.026	1.023	1.027	1.022
7	1.024	1.022	1.027	1.022
8	1.044	1.042	1.048	1.042
9	1.004	1.003	1.005	1.002
10	0.984	0.983	0.984	0.983
11	0.984	0.983	0.984	0.983
12	0.992	0.991	0.991	0.992
13	0.978	0.977	0.978	0.977
14	0.970	0.970	0.970	0.970
15	0.988	0.987	0.988	0.987
16	0.991	0.989	0.990	0.991
17	0.993	0.991	0.992	0.991
18	1.026	1.024	1.030	1.023
19	0.988	0.987	0.989	0.987
20	0.977	0.977	0.976	0.977
21	1.015	1.015	1.016	1.014
22	1.015	1.015	1.016	1.015
23	1.014	1.014	1.015	1.014
24	1.017	1.016	1.018	1.016
25	1.001	1.000	1.002	1.00
26	0.976	0.975	0.977	0.975
27	1.013	1.011	1.015	1.011
28	1.033	1.031	1.035	1.031
29	1.050	1.048	1.023	1.048
30	0.980	0.979	0.981	0.979
31	0.951	0.950	0.952	0.950
32	0.960	0.959	0.961	0.959
33	0.958	0.957	0.958	0.957
34	0.967	0.966	0.967	0.966
35	0.973	0.973	0.974	0.973
36	0.982	0.982	0.983	0.982
37	0.991	0.990	0.991	0.990
38	1.016	1.016	1.017	1.016
39	0.989	0.988	0.989	0.988
40	0.980	0.979	0.980	0.979
41	1.007	1.006	1.007	1.006
42	0.975	0.974	0.975	0.974
43	1.020	1.019	1.020	1.019
44	1.019	1.018	1.019	1.018
45	1.035	1.033	1.035	1.033
46	1.060	1.060	1.060	1.060
47	1.034	1.036	1.035	1.036
48	1.029	1.030	1.030	1.030
49	1.038	1.037	1.038	1.037
50	1.024	1.023	1.024	1.023
51	1.052	1.051	1.052	1.051
52	1.019	1.017	1.021	1.017
53	1.009	1.007	1.011	1.007
54	1.029	1.027	1.031	1.027
55	1.059	1.057	1.059	1.057
56	0.975	0.974	0.975	0.974
57	0.970	0.970	0.970	0.970

From Table.5 it is observed that the voltage at bus 2 is controlled from 1.008 to 1.005, 1.006 and 1.004 with SVC, TCSC and UPFC respectively. Similarly all the bus voltages are controlled within the stationery limits.

VIII. Conclusion

In this paper, GA based reducing generating cost in transmission system using FACTS devices is done to increase power system load ability, annual saving and voltage profile. The annual savings was calculated by considering the operating conditions which effectively works in analyzing the annual saving of the system. From the results it is clearly evident that the proposed technique is increased overall annual savings and overall voltage profile of the system also controlled.

The proposed problem can also test with fuzzy approach, neuro fuzzy etc., for future work.

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