Optimal Location and Sizing of FACTS Controllers in Transmission System Using Genetic Algorithm Under Contingency Condition

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Abstract.

With ever increasing power in the power systems optimal sizing and location of Flexible AC Transmission Systems is necessary to compensate these power dynamics. This paper presents optimal location of Flexible AC Transmission System's (FACTS) devices in a transmission system under N-1 contingency condition. Location of FACTS device is at the most contingent bus in the transmission system. Sizing, choice of different FACTS devices and location in a standard power system topology are exploited using Genetic Algorithm (GA). GA based optimization of sizing of single and multiple FACTS devices is carried out using simulation in MATLAB on IEEE 9 bus system. Results indicate effectiveness in fuel cost saving and loss minimization under contingency condition with optimal location of FACTS controllers. Placement of multiple FACTS devices using GA is found to be efficient.

Keywords. Genetic Algorithm, FACTS, N-1 Contingency, TCSC, SVC

1. INTRODUCTION

Contingency analysis being an important security analysis for power system, needs quick and effective counter measure. FACTS devices are capable of compensating these contingency conditions. FACTS devices include Static Synchronous Compensator (STATCOM), Thyristor Controlled Synchronous Compensator (TCSC), Static Var Compensator (SVC), Unified Power Flow Controller (UPFC) and are incorporated in the transmission system by optimizing the compensation using evolutionary computational algorithms [1]. GA is applied to optimize the MVAR injection in a IEEE 30 bus system [2]. Literature [3] discusses Particle Swarm Optimization (PSO) and GA. A new approach with Improved Teaching Learning Based Optimization (ITLBO) and Weight Improved Partial Swarm Optimization (WIPSO) estimating optimal location viz a viz parameter setting of UPFC and SVC are developed and implemented on IEEE 14 bus system [4]. Power system problems that include overloading and voltage limit violation is mitigated using Biogeography Based Optimization (BBO) [5] by optimal location of UPFC and Interline Power Flow Controller (IPFC) . Optimal location and the parameter setting of

UPFC under N-1 contingency criterion is optimized using "Artificial Algae Algorithm" (AAA) [6]. In [7], the total hourly generation cost of generator units is minimized to meet load demand and system losses using Real Coded GA and PSO methods. In [8], PSO and GA are used for the analysis of OPF. The Minimization of the average load-ability on all transmission lines is considered as the objective function. Mitigation of line overload problem during contingency by optimal placement of FACTS devices is developed monitoring both real power flow performance index(PI) and contingency severity index(CSI)[10].TCSC and UPFC are considered and modelled for steady-state analysis. After the location is determined, their type, their optimal settings and cost of installation are obtained by solving the optimization problem using GA. Optimal reallocation of generators is proposed in [11] for the management of contingency condition in the power system. Sizing is carried using Krill Herd Algorithm and optimal power flow is obtained in the presence of TCSC. The contingency analysis is performed using Rapid contingency ranking technique. A planning model to optimally allocate TCSCs in the transmission network under N -1 contingency is developed using the reformulation technique that linearizes the nonlinear power flow problem with constraints [12]. In [13], power system stability, minimum power loss with voltage stability is used as an index for optimal allocation of the controllers. First SVC is placed based on model analysis using GA in a power system. After placing the SVC based on minimum power loss with voltage stability index, the most appropriate location and size of SVC is found. PSO to find the optimal location of multi-type FACTS devices in a power system to alleviate the line over loads is developed [14]. The optimization is performed to locate different FACTS devices with their ratings with installation cost for single and multiple contingencies. TCSC, SVC and UPFC are considered and modelled for steady-state analysis to improve system security criteria for optimisation. The optimal location of TCSC is found in[15] by performance indices calculation to reduce overloading of each transmission line in normal case and under contingency condition. Review of various FACTS devices are discussed with its application in power system [16]. PSO is used to find optimal location and the optimal parameter settings of TCSC under single line contingency (N-1 contingency) [17]. Contingency analysis is performed to detect and rank the severest line faulted contingencies in a power system. Power system get restructured based on the market conditions. Optimal allocation of multiple FACTS in this restructured system with wind generator is developed that maximizes profit by minimizing device investment and operating cost under normal and contingency conditions [18]. Two reliable and efficient evolutionary-based methods named Shuffled Frog Leaping Algorithm (SFLA) and Grey Wolf Optimizer (GWO) to solve Optimal Power Flow (OPF) problem is developed [19]. Shunt and series compensation devices are integrated to be able to both regulate voltage and enhance line loadability in the transmission line [20].

2. SVC AND TCSC MODEL

Shunt and the series compensator is shown in Figure 1. The reactive power model is used for SVC is the shunt compensator. And reactance model is used for TCSC acting as the series compensator.

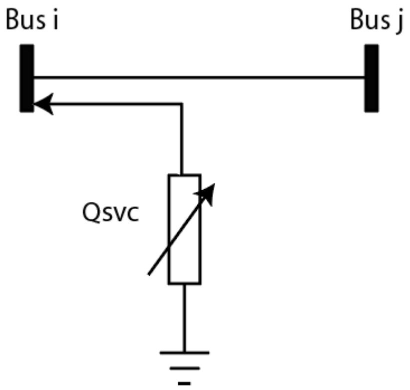

Figure 1(a) : SVC model

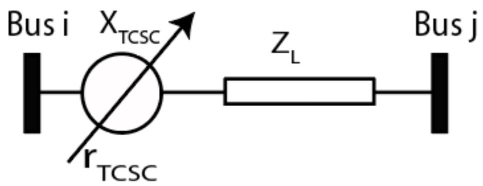

Figure 1(b): TCSC model

The value of reactance is the function of reactance of the line where the TCSC is placed. The impedance of the transmission line

$$Z_{ij} = Z_L + jX_{TCSC} \tag{1}$$

$$X_{TCSC} = r_{TCSC} X_L \tag{2}$$

Where

$Z_L - transmission\ line\ impedance$

$X_{TCSC} - reatance\ of\ hte\ line\ where$

$TCSC\ is\ located$

$r_{TCSC} - compensation\ degree\ of$

$TCSC\ (Coefficient)$

The FACTS device SVC is operated as both inductive and capacitive mode and control bus voltage by absorbing or injecting reactive power. A shunt variable susceptance added at both ends of the line for model the SVC. The injected reactive power at bus i is

$\Delta Q_{is} = Q_{svc}$ (3)

$\mathrm{Q_{svc}}$ − reative power injected by SVC in MVAR

$\mathrm{Q_{svc} - Q_{Min}} \sim$ Qmax (4)

The constraint limit of the TCSC is,

$X_{TCSC} = X_{Lmin}\ to\ 0.7\ X_{Lmax}$ (5)

$Q_{svc} = Q_{svc\ min}\ to\ Q_{svc,max}$ (6)

Operational Cost Optimization Problem Formulation

The objective function is minimization of total fuel cost and is given in Equation 1.

$$Minimize\ F_{cost}(P_g) = \sum_{i=1}^{N_g} x{P_{g_i}}^2 + yP_{g_i} + z \quad (7)$$

Where P_{g_i} is power generated at 'ith' generator, $F_{cost}(P_g)$ is the total fuel cost, x, y, z are the cost coefficients.

$\mathrm{V_{i\ min}} < \mathrm{V_i} < \mathrm{V_{i\ max}}$ (8)

$\mathrm{V_{i\ min}}$ 0.9 p.u and $\mathrm{V_{i\ max}}$ 1.1 p.u.

Impedance variation of TCSC is limited to 70% of the line impedance in capacitive and 20% inductive. Impedance range is represented in Equation (3).

$$X_{TCSC} = -0.8\ X_L \leq X_L \leq 0.2\ X_L \quad (9)$$

MVAR injection the SVC can apply in the line is limited to 100MVAR in both the directions meaning it can inject or absorb maximum of 100MVAR from and to the line.

$$Q_{svc} = -100MVAR \leq Q_{svc} \leq 20MVAR \quad (10)$$

Power balance Equation acting as the equality constraint is as given in Equation (11).

$P_{Load} + P_{Loss} - \sum_{i=1}^{N_g} P_{gi} = 0$ (11)

P_{Load} – Total Demand in entire power system.

P_{Loss} – total line loss in entire power system.

3. FACTS Sizing and Placement

Generator and line outage condition is applied for the N-1 contingency condition. The power flow equation in a transmission line is

$$P = \frac{V_1 V_2}{X} sin\delta \quad (12)$$

GA flowchart used for the proposed implementation is given in Figure 2.

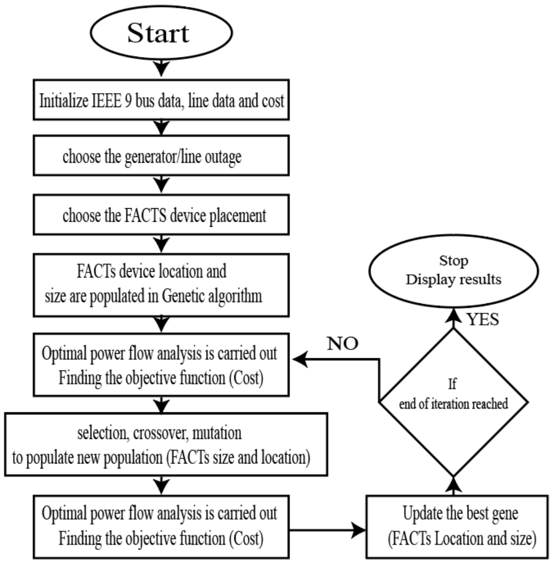

Figure 2: Overall implementation details of the optimization algorithm for outage mitigation

4. RESULTS AND DISCUSSIONS

MATLAB based simulation is carried out with different cases in the FACTS placement scenario. The table that would define all the cases is listed in Table 1.

Table1. Cases Used in the Proposed FACTS Sizing Algorithm

Cases	**Load Flow Conditions**
Case1	Without any FACTS Device; Without contingency; With Line Outage; With Generator Outage
Case2	SVC; Without contingency; With Line Outage; With Generator Outage
Case3	TCSC; Without contingency; With Line Outage; With Generator Outage
Case4	TCSC and SVC; Without contingency; With Line Outage; With Generator Outage

Network consists of 3 Generators, nine branches, 3 Transformers & 6 Transmission lines respectively.

The total cost of generation is determined by performing OPF without any FACTS controllers, without and with contingency condition (Line outage, generator outage) for the base case study (case-1). Seven different cases of individual and combined FACTS controllers (SVC and TCSC) are tested and for each case, total generation cost, total system loss and real power generation of generators are given in Table-5. Further, for each TCSC & SVC setting and for each case, optimal locations of FACTS controller with ratings and total power generation are given in Table-2. Results are discussed case wise.

Table 2: Generation Cost and Transmission Loss without Outage

CASE-1: In this case, without incorporating FACTS controllers & without outage gives the TSL is 3.80744 corresponding generation cost is 5309.486 $/hr. It is observed that under each line outage and Generator outage TSL will be quite high and corresponding generation cost increases. Hence it is decided to locate FACTS controllers based on the minimum Generation cost rather than minimum TSL.

CASE-2: a) Without outage: SVC located at bus 5 with 74.6237 MVAR gives better generation cost savings with 3.986 $/hr (34917.36 $/yr). The corresponding reduction in system loss is found to be 0.14334 MW. The results are tabulated in Table 2.

b) With line outage: It is observed that under line outage, each line outage gives more promising reduction in cost of generation. The corresponding system loss is also reduced. Location of SVC and its ratings shown in Table 3. For each line outage reduction in generation cost /hr., generation cost/year and corresponding reduction in system loss is tabulated shown in Table3.

Sl. No	Types of FACTS Controllers	TCSC Compensation Setting	Reduction in generation		Loss reduction in system
			Generation Cost in $/hr	Generation cost in $/yr	System Loss MW
1	SVC	--------	3.986	34917.36	0.14334
2	TCSC	50%	2.286	20025.36	0.05784
		70%	2.686	23529.36	0.07814
3	SVC & TCSC	50%	4.186	36669.36	0.12914
		70%	4.886	42801.36	0.22804

c) With Generator outage: It is also observed that under each generator outage except reference bus the cost of generation is reduced. The corresponding system loss also reduced. Location of SVC and its ratings shown in table 3. For each Generator outage reduction in generation cost /hr, generation cost/year and corresponding reduction in system loss is tabulated shown in Table 3.

CASE-3:a) Without outage: Location of TCSC in the line 9-4 is not varying irrespective of TCSC settings. Increase in TCSC compensation setting will reduce the generation cost and TSL. The transmission line 9-4 is found to be location of TCSC with 51.56 MVAR compensation settings gives optimal generation cost savings of 2.686 $/hr. The corresponding reduction in TSL is found to be 0.07814 MW

Table 3: Line outage & Generator outage with SVC

Sl. No	Line No.	Reduction in Generation		Loss reduction in system
		Generation Cost in $/hr	Generation cost in $/yr	System Loss MW
Line Outage				
1	Line-2	6.96	60969.6	0.37743
	Line-3	10.87	95221.2	0.3099
	Line-5	7.66	67101.6	0.34544
	Line-6	10.94	95834.4	0.49689

	Line-8	29.29	2,56,580	0.07688
	Line-9	28.22	247207.2	1.32221
Gen Outage				
2	Gen2	4.26	37317.6	0.10056
	Gen3	7.49	65612.4	0.22323

b) With line outage: It is observed that Location of TCSC varies in line 2 (line 4-5) with different compensation setting. TCSC with 8-9 and 9-4 are found to be more promising reduction in cost/hr and corresponding reduction in TSL are shown in Appendix III (Table -8). Compensation setting and location is tabulated in Table4.

c) With Generator outage: TCSC Location is same for different compensation setting. TCSC in line 9-4 gives better generation cost savings and also corresponding TSL reduction is shown in Table-4. Compensation setting and location is tabulated in Table4

CASE-4: **a) Without outage**: Location of TCSC varies with different compensation settings in the transmission line 9-4 for minimum compensation & 5-6 for Maximum compensation and no changes in the location of SVC. Location of TCSC in line 5-6 is found to be better generation cost savings of 4.886 $/hr. Corresponding reduction in TSL found to be 0.22804.

b) With line outage: It is observed that location of TCSC is changes in line 5 under different line outage, but the location of SVC is same for various compensation setting. In 70% (Maximum) compensation setting gives more promising reduction in generation cost/hr and reduction in system loss is tabulated in Table 5.

c) With Generator outage: Location of SVC in Generator outage is same, TCSC placement is not identical in case of Generator 3 outage of different TCSC compensation setting. In 70% (Maximum) compensation gives more promising reduction in cost/hr and corresponding reduction in loss is tabulated in Table 5.

The stochastic nature of the injected MVAr is exploited in the meta-heuristics methods to populate the different reactive power injection at different lines to find the optimal position that exhibits better overall losses of the complete bus system.

Table 4: Line outage & Generator outage with TCSC

Sl. No	Line No.	50% COMPENSATION			70% COMPENSATION		
		Reduction in generation		Loss reduction in system	Reduction in generation		Loss reduction in system
		Generation Cost in $/hr	Generation cost in $/yr	System Loss MW	Generation Cost in $/hr	Generation cost in $/yr	System Loss MW
Line Outage							
1	Line2	2.76	24177.6	0.10333	3.26	28557.6	0.15543
	Line3	5.97	52297.2	0.0386	6.47	56677.2	0.0935
	Line5	2.26	19797.6	0.10274	2.46	21549.6	0.12504
	Line6	4.54	39770.4	0.08679	5.04	44150.4	0.09769
	Line8	13.29	116420.4	0.01568	21.99	192632.4	0.44768
	Line9	25.12	220051.2	1.29321	32.02	280495.2	1.35441
Gen Outage							
2	Gen2	7.76	67977.6	0.19156	8.26	72357.6	0.19896
	Gen3	7.99	69992.4	0.25733	9.79	85760.4	0.30053

Table 5: Cost and Loss analysis with Line Outage SVC and TCSC

Sl. No	Line No.	50% COMPENSATION			70% COMPENSATION		
		Reduction in generation		Loss reduction in system	Reduction in generation		Loss reduction in system
		Generation Cost in $/hr	Generation cost in $/yr	System Loss MW	Generation Cost in $/hr	Generation cost in $/yr	System Loss MW
Line Outage							
1	Line-2	6.56	57465.6	0.31383	9.16	80241.6	0.39713
	Line-3	11.57	101353.2	0.2396	14.17	124129.2	0.5328
	Line-5	5.56	48705.6	0.15614	8.26	72357.6	0.28624
	Line-6	14.14	123866.4	0.56919	15.74	137882.4	0.61619
	Line-8	18.09	158468.4	0.45058	26.89	235556.4	0.76578
	Line-9	42.22	369847.2	1.77241	44.52	389995.2	2.00781
Gen Outage							
2	Gen2	9.96	87249.6	0.24146	10.16	89001.6	0.26296
	Gen3	13.19	115544.4	0.39163	14.29	125180.4	0.43913

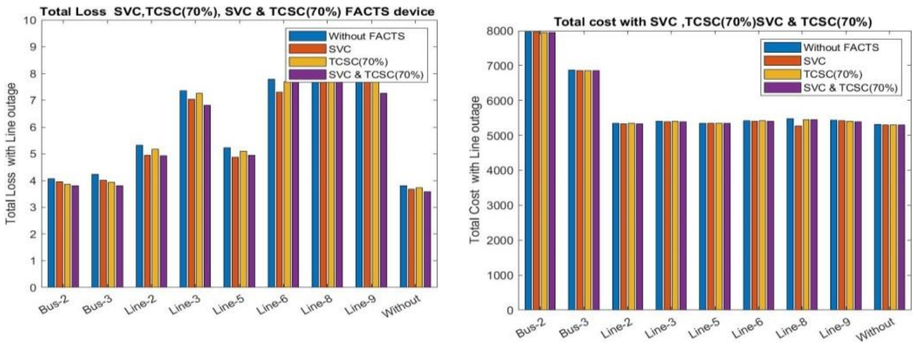

Figure3 : Reduction of total cost and losses in the 9-bus system with Facts controllers under contingency condition

It can be inferred that the SVC has performed better for the line outage conditions and at the same time TCSC has performed during the generator outage conditions. But while the combination of both TCSC and SVC is used the performance for both the outage condition is found to be better while individual FACTS Controllers are incorporated. The rare observation in the Table 3 &Table 4 is that the single TCSC and SVC has better performance even while compared to SVC & TCSC. It can be observed that the contingency while both the line outage and the generator outage occurs in the IEEE 9 bus system the total cost is observed to be reduced for SVC installation than the TCSC installation for the best possible setting of each of the FACTS devices. Total power generated (PG), total loss and the total cost /hr is tabulated for different configuration of SVC, TCSC and combined SVC and TCSC.

5. CONCLUSION:

The optimized placement of single and multiple FACTS devices in the standard IEEE 9 bus system is carried out. The overall fuel cost is reduced. The tradeoff is that the generation outage allows only lesser loss the cost of the generator outage is seen to be higher. The placement of multiple FACTS devices obtains the lesser overall cost and compared to the cost incurred when only single FACTS devices is installed. The overall optimization algorithm on the FACTS compensated contingency analysis is found to be satisfactory.

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