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A Solution to the Security Constrained OPF Problem using Intelligent Search Evolution Algorithm with FACTS Device

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Abstract

The static synchronous series compensator (SSSC) is one of the converter based flexible alternating current transmission systems (FACTS) device. This paper presents a new intelligent search evolution algorithm (ISEA) to solve security constrained optimal power flow (SCOPF) problem with SSSC. Unlike the SCOPF solution methods existing in the literature, in the proposed algorithm, a two step initialization process have been adopted and the mutation operation is not required. Further, it gives optimal solution with less number of generations. The proposed algorithm has been tested on a standard IEEE-30 bus system to solve SCOPF problem without and with SSSC. The test results indicate that the SCOPF solution with SSSC is better than without SSSC.

Keywords: Flexible alternating current transmission systems, security constrained optimal power flow, optimization techniques, and contingency analysis.

Introduction

The static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), unified power flow controller (UPFC) and interline power flow controller (IPFC) are the converter based FACTS devices. These FACTS devices employ the voltage source converter as a basic building block. The theory, modeling and applications of SSSC using an Electromagnetic Transient Program (EMTP) simulation package has been described [1]. The optimal power flow problem with converter based FACTS controllers by Nonlinear Interior Point method has been discussed [2]. A multi control functional model of static synchronous series compensator (SSSC) used for steady state control of power system parameters with current and voltage operating constraints has been presented [3]. Different models of SSSC for power flow analysis have been reported [4]-[7]. Further, it has been shown that the power injection model (PIM) of FACTS devices is a powerful model than other models [8]-[9].

Ref. [10] presents a rule-based optimal power flow with phase shifter approach to enhance power system security. An approach for determining the most suitable locations for installing thyristor controlled series capacitor (TCSC) in order to eliminate line overloads under a single line contingency is proposed [11]. An approach for selection of unified power flow controller (UPFC) suitable locations considering normal and network contingencies has been presented and the ranking is evaluated using composite criteria based fuzzy logic for eliminating masking effect [12]. The other optimization methods to find the solution for SCOPF problem have been discussed [13]-[15]. Careful study of the former literature reveals that there is a single step initialization process along with mutation operation. But, in the proposed algorithm the initialization is done in two steps, the mutation operation is not required and also it gives better solution with less number of generations. The feasibility of the proposed algorithm is demonstrated for a standard IEEE-30 bus system without and with SSSC. The obtained SCOPF results are compared without and with SSSC. The results reveal that best solution obtained by the proposed algorithm with SSSC is quite encouraging and useful in optimal power flow environment.

Power Injection Model of SSSC

The basic structure of Static Synchronous Series Compensator (SSSC) is shown in Fig.1. It usually consists of a solid state voltage source converter, a dc link capacitor and a coupling transformer. The converter is connected in series with the transmission line through series coupling transformer. In principle, the SSSC can generate and insert a series voltage, which can be regulated to change the impedance (more precisely reactance) of the transmission line. When the series injected voltage leading the line current, it emulates an inductive reactance causing the power flow and the line current to decrease as the level of compensation increases. When the series injected voltage lagging the line current, it emulates a capacitive reactance causing the power flow and the line current to increase as the level of compensation increases. In this way, the power flow on the transmission line or the voltage of the bus, which the SSSC is connected, can be controlled. The detailed model of SSSC can be obtained [16]-[17].

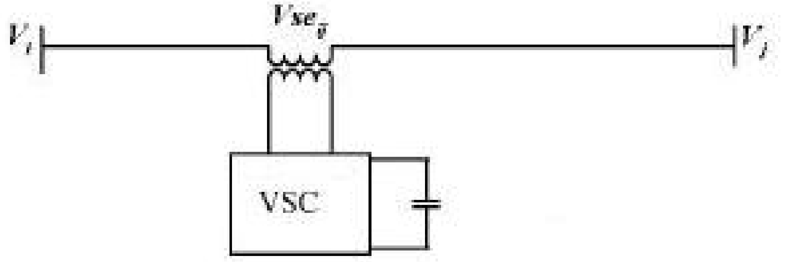

Figure 1: Schematic diagram of SSSC

Formulation of the SCOPF Problem with SSSC

In this article, minimization of fuel cost is considered as an objective function to examine the performance of the proposed algorithm without and with SSSC. The optimal solution must satisfy all the equality, inequality and security constraints. The SCOPF problem with SSSC is expressed as follows:

$$\text{Min} \sum_{i=1}^{ng}(a_i P_{gi}^2 + b_i P_{gi} + c_i) \ \$/h \qquad (1)$$

Subject to

$$Pg_i - Pd_i - \sum_{j=1}^{nb} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) + P_{inj,m} = 0 \qquad (2)$$

$$Qg_i - Qd_i + \sum_{j=1}^{nb} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) + Q_{inj,m} = 0 \qquad (3)$$

$$Pg_i^{\min} \le Pg_i \le Pg_i^{\max} \qquad i = 1, 2,.., ng \qquad (4)$$

$$Qg_i^{\min} \le Qg_i \le Qg_i^{\max} \qquad i = 1, 2,.., ng \qquad (5)$$

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad i = 1, 2,.., nb \qquad (6)$$

$$T_i^{\min} \le T_i \le T_i^{\max} \qquad i = 1, 2,.., nt \qquad (7)$$

$$Qc_i^{\min} \le Qc_i \le Qc_i^{\max} \qquad i = 1, 2,.., nc \qquad (8)$$

$$Vse^{\min} \le Vse \le Vse^{\max} \qquad (9)$$

$$\theta se^{\min} \le \theta se \le \theta se^{\max} \qquad (10)$$

$$S_l \le S_l^{\max} \qquad l = 1, 2,.., nl \qquad (11)$$

Intelligent Search Evolution Algorithm (ISEA)

The intelligent search evolution algorithm tries to approach the target in an optimal manner for finding the optimal or near optimal solution to any mathematical optimization problem. The major stages of the proposed algorithm are briefly described as follows:

Two Step Initialization

The population is generated by using the following equation

$$x_{i,j} = x_j^{\min} + rand\,(0, 1)\quad (x_j^{\max} - x_j^{\min}) \qquad (12)$$

where $i = 1, 2,.., ps$ and $j = 1, 2,.., ncv$.

ps = population size.

ncv = number of control variables.

$x_j^{\min}$ & $x_j^{\max}$ are the lower and upper bounds of j^{th} control variable.

rand (0, 1) is a uniformly distributed random number between 0 and 1.

The two step initialization process provides better probability of detecting an optimal solution to the power flow equations that would globally minimize a given objective function. In the first step, initial population is generated as a multi-dimensional vector of size (*ps* × *ncv)* and it is considered as a village. Evaluate the value of cost function for each string in the village and select the best string from the village corresponding to minimum cost. Repeat the procedure for number of villages (*nv*). In the second step, combine all the best strings from each village to form multi-dimensional vector of size (*nv* ×*ncv)* and this new population is used for evolutionary operations.

Recombination

In this study, an efficient recombination operator has been used so that search along variables is also possible. If $x_i^{(j)}$ and $x_i^{(k)}$ are the values of variables x_i in two strings *j* and *k*. The crossover between these two values may produce the following new value

$$x_i^{new} = (1-\lambda)\, x_i^{(j)} + \lambda\; x_i^{(k)} \qquad (13)$$

Selection

For the present work, sorting and ranking selection procedure is used.

Stopping Criteria

In the current work, the number of generations reaches the given maximum number of generations is used as stopping criteria.

Results and Discussions

In this section, a standard IEEE 30-bus system [18] has been considered to demonstrate the effectiveness and robustness of ISEA (proposed algorithm) without and with SSSC. In 30-bus test system, bus 1 is considered as slack bus, while bus 2, 5, 8, 11 and 13 are taken as generator buses and other buses are load buses. As a preliminary computation, the contingency analysis and ranking is performed on the test system. For each single line outage, the number of over loaded lines (NOLL) and the number of voltage violation buses (NVVB) are identified and then ranking is given. The ranking for five most severe contingencies is given in table 1. From table 1, it can be found that the line-1 outage is the most severe contingency which is ranked as 1. In this paper, rank1 contingency is considered to investigate the effectiveness of the proposed algorithm without and with SSSC to eliminate the overloaded lines and bus voltage violations. The input parameters of ISEA for the test system are given in table 2. The converter of SSSC is placed in a line between the buses 29-30, nearer to bus 30. A MATLAB program is implemented for the test system on a personal computer with Intel Pentium dual core 1.73 GHz processor and 512 MB RAM. Five runs have been performed for the test system. The security constrained optimal solution results over these five runs have been tabulated. The line flows and bus voltages of test system for rank1 contingency using proposed algorithm without and with SSSC are given in table 3 and 4 respectively.

From table 3, it can be observed that the overloaded lines are eliminated using SCOPF solution without and with SSSC. Similarly, from table 4, it can also be observed that the bus voltage violations are eliminated using SCOPF solution without and with SSSC. Also, from table 4, it is clear that the voltage profiles have been improved because of SSSC. Further, the security constrained optimal power flow solution for IEEE 30-bus system is calculated using proposed method without and with SSSC. The comparison of SCOPF results are shown in Table 5 and the optimal SSSC parameters obtained from the SCOPF solution of test system are given in Table 6. From Table 5, it can be seen that total active power generation required and power loss has been reduced because of SSSC. Further, it is observed that there is a significant reduction in the cost because of SSSC.

Table 1: Ranking for five most severe contingencies of IEEE 30 bus system

Outage line From bus-To bus	NOLL	NVVB	Performance index PI=NOLL+NVVB	Rank
1-2	4	5	9	1
28-27	3	5	8	2
2-5	6	0	6	3
3-4	4	1	5	4
27-29	2	2	4	5

Table 2: Input parameters of ISEA for IEEE 30 bus system

S.No	Parameters	Quantity
1	Number of villages	5
2	Population per village	5
3	Recombination constant(λ)	0.5
4	Number of iterations	10

Table 3: Line flows of IEEE 30 bus system for rank1 contingency

Line	Line flow(MVA)			Line flow
From bus-To bus	Base case	SC OPF without SSSC	SC OPF with SSSC	limit(MVA)
1-3	314.684	125.912	124.035	130
3-4	277.513	121.309	118.335	130
4-6	171.631	75.849	74.419	90
6-8	39.743	4.849	11.579	32

Table 4: Bus voltages of IEEE 30 bus system for rank1 contingency

Bus No.	Voltage magnitude (p.u)			Voltage limits (p.u)	
	Base case	SC OPF without SSSC	SC OPF with SSSC	Vmin	Vmax
3	0.933	1.001	1.021	0.950	1.050
4	0.936	1.000	1.018	0.950	1.050
26	0.941	0.967	0.969	0.950	1.050
29	0.943	0.986	0.989	0.950	1.050
30	0.931	0.970	0.975	0.950	1.050

Table 5: SCOPF solution for rank1 contingency of IEEE 30 bus system using ISEA without and withSSSC

S.No	Parameter		SC OPF without SSSC	SC OPF with SSSC
1	Real power generation (MW)	PG1	125.172	123.800
		PG2	62.943	68.960
		PG5	27.438	25.463
		PG8	29.442	31.379
		PG11	23.788	18.003
		PG13	27.807	28.295
2	Generator voltages (p.u)	VG1	1.016	1.047
		VG2	1.022	1.034
		VG5	1.012	1.027
		VG8	0.998	1.006
		VG11	1.034	0.999
		VG13	1.058	1.061
3	Total real power generation (MW)		296.590	295.932
4	Total real power loss (MW)		13.190	12.532
5	Total cost ($/h)		854.250	852.161

Further, the comparison of convergence characteristics without and with SSSC is shown in Fig.2 for rank1 contingency. From this, it can be seen that, as the number of iterations increase, the cost decreases and it is nearly constant above 5 iterations with out and with SSSC, which indicates that the number of iterations required for the proposed method is less.

Table 6: SSSC parameters of IEEE 30 bus system for rank1 contingency

S.No	Parameter	Quantity
1	*Vse* (p.u)	0.138
2	θ*se* (deg.)	82.925

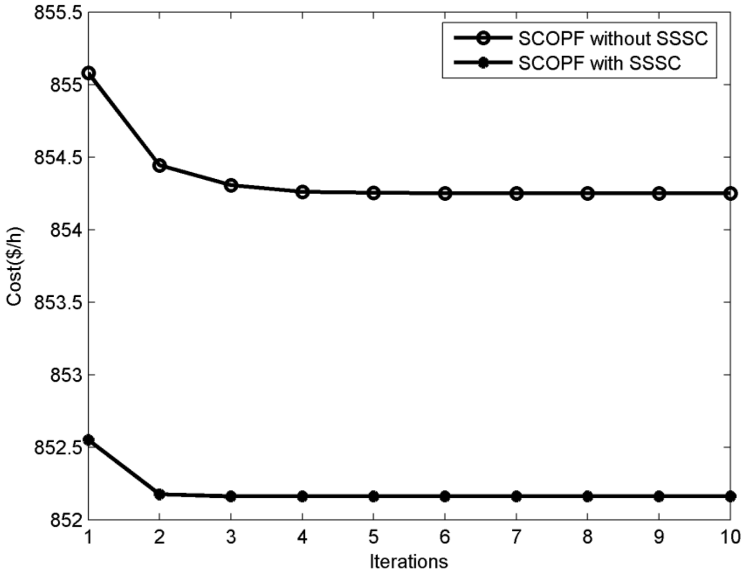

Figure 2: Comparison of convergence characteristics of IEEE 30 bus system using ISEA without & with SSSC under rank1 contingency

Conclusion

In this paper, an intelligent search evolution algorithm has been proposed to solve security constrained optimal power flow problem in the presence of static synchronous series compensator. The proposed algorithm employs a two step initialization process and there is no need of mutation operation. The results demonstrate the effectiveness and robustness of the proposed method. The SCOPF results obtained for test system using the proposed method without and with SSSC are compared and observations reveal that the overloaded lines and bus voltage violations are eliminated. Also, the voltage profiles have been improved, the generation cost and power losses are less with SSSC. Further, it is clear that the proposed method gives optimal solution with less number of generations.

References

[1] Kalyan K.Sen, “SSSC-Static synchronous series compensator: Theory, Modeling and Applications, ” *IEEE Trans. Power Del.,* vol.13, no. 1, pp. 241–246, Jan.1998.

[2] X.P. Zhang and E.Handschin, "Optimal power flow control by converter based FACTS controllers, " *in Proc.7th* Int. Conf. AC-DC Power Trans., London, U.K., Nov.28- 30, 2001.

[3] X.P. Zhang, "Advanced modeling of the multicontrol functional static synchronous series compensator (SSSC) in Newton power flow, " *IEEE Trans. Power Syst.,* vol.18, no. 4, pp.1410–1416, Nov.2003.

[4] ZHAO Jianjun, GUO Jianbo and ZHOU Xiaoxin, “Modeling of static synchronous series compensator in Newton power flow calculation in PSASP, ” *IEEE/PES Transm. Distrib. Conf. and Exhibition,* Dalian, China, 2005.

[5] Yankui Zhang and Yan Zhang, “A novel power injection model of embedded SSSC with multi-control modes for power flow analysis inclusive of practical constraints, ” *Electric Power Syst. Res.,* vol. 76, pp. 374–381, 2006.

[6] Amany El-Zonkoly, “Optimal sizing of SSSC controllers to minimize transmission loss and a novel model of SSSC to study transient response, ” *Electric Power Syst. Res.,* vol. 78, pp. 1856–1864, 2008.

[7] Vinkovic A and Mihalic R, “A current-based model of SSSC for Newton–Raphson power flow, ” *Electric Power Syst. Res.,* vol. 10, pp. 1806 –1813, 2008.

[8] J.Y.Liu, Y.H.Song and P.A.Mehta, “Strategies for handling UPFC constraints in steady state power flow and voltage control, ” *IEEE Trans. Power Syst.*, vol.15, no.2, pp. 566-571, 2000.

[9] Y.Xiao, Y.H.Song and Y.Z.Sun, “Power injection method and linear programming for FACTS control, ” *IEEE Power Engg.*, society winter meeting, vol.2, pp. 877-884, 2000.

[10] James A.Momoh, Jizhong Z.Zhu, Garfield D.Boswell and Stephen Hoffman, “Power system security enhancement by OPF with phase shifter, ” *IEEE Trans. Power Syst.,* vol.16, no.2, pp. 287-293, May 2001.

[11] Yunqiang Lu and Ali Abur, “Static security enhancement via optimal utilization of thyristor controlled series capacitors, ” *IEEE Trans. Power Syst.,* vol.17, no.2, pp. 324-329, May 2002.

[12] D.Thukaram, L.Jenkins and K.Visakha, “Improvement of system security with unified power flow controller at suitable locations under network contingencies of interconnected systems, ” *IEE Proc.- Gener.Transm.Distrib.,* vol.152, no.5, pp.682-690, Sept.2005.

[13] W.Shao and V.Vittal, “LP-based OPF for corrective FACTS control to relieve over loads and voltage violations, ” *IEEE Trans. Power Syst.,* vol.21, no.4, pp.1832-1839, Nov.2006.

[14] A.Shunmugalatha and S.M.Raja Slochanal “Optimum cost of generation for maximum load ability limit of power system using hybrid particle swarm optimization, ” *Electrical Power and Energy Syst.,* vol. 30, pp.486-490, 2008.

[15] G.Baskar and M.R.Mohan “Contingency constrained economic load dispatch using improved particle swarm optimization for security enhancement, ” Electric Power Syst. Research, vol. 79, pp.615-621, 2009.

[16] A.V.Naresh Babu, S.Sivanagaraju, and T.Ramana, “Use of static synchronous series compensator for power flow control in power systems, ” International Journal of Electrical Engineering and Electrical Systems, vol.2, no.1, pp.1-9, June 2010.

[17] A.V.Naresh Babu, S.Sivanagaraju and T.Ramana, “Mathematical modelling, analysis and effects of static synchronous series compensator (SSSC) parameters in power flow studies, ” Proc. of Int. Conf. on Machine Intelligence Application to Power Signal Processing Communication and Control (MIPSCCON), GMRIT, Rajam, Andhra Pradesh, India, April 2011.

[18] IEEE 30-bus system data available at http://www.ee.washington.edu/research/pstca.