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Congestion Management through Optimal Placement of SSSC using Modified Gravitational Search Algorithm

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***Abstract**: This paper describes optimal placement of static synchronous series compensator (SSSC) in power grid using modified gravitational search algorithm. Control of bus voltages and regulation of power flow is achieved through voltage injection model of SSSC. A multi objective optimization through modified gravitational search algorithm is used to improve voltage profile of buses, minimize line losses and minimize cost of investment of SSSC. The modified gravitational search algorithm provides superior quality solutions with faster convergence. The effectiveness of this proposed algorithm is tested on IEEE-57 test bus system.*

***Keywords**: SSSC, optimal placement of SSSC, modified gravitational search algorithm, multi objective optimization, investment cost of SSSC, voltage stability.*

I. Introduction

Deregulation of electricity sector has resulted in emergence of multiple players in generation, transmission and distribution. Maintenance of voltage stability, reliability and security becomes a major concern for system operator. Voltage stability not only affects system reliability but also affects transfer of power in grid [1]. A sustained condition of voltage instability may lead to voltage collapse [2]. Hence, occurrence of such conditions in a power network is prevented by several techniques. Use of static synchronous series compensator (SSSC) is one such technique to build a robust power system. The improved voltage stability helps to mitigate congestion on the transmission lines by regulation of power flow due to robust voltage stability [3].

Various meta heuristic search algorithms are used for optimization of system parameters such as genetic algorithm, particle swarm algorithm, firefly algorithm, ant colony algorithm etc. All these algorithms are used to treat specific class of problems and are fairly successful. Gravitational search algorithm is one such algorithm which has been modified to yield better quality solutions with faster convergence. This new algorithm is used to optimally place SSSC in IEEE-57 test bus system. The results obtained are encouraging.

The following sections deal with brief literature review (section-II) followed by modeling of SSSC (section-III), problem formulation (section-IV) and result and discussion (section-V). Conclusion is given in the section -VI.

II. Brief Literature Review

Stability and security of power network is affected by voltage stability. SSSC can play a major role in ensuring voltage stability of a power network. Various devices such as SVC (static var compensator) [4], STATCOM (static synchronous compensator) [5] and UPFC (unified power flow controller) [6] have been used for stabilization of bus voltages by optimal placement in a power network.

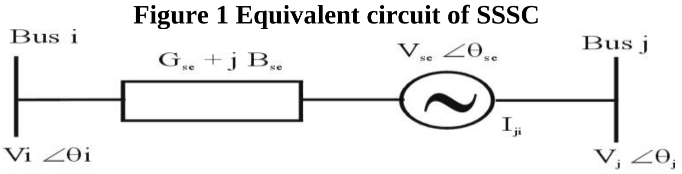
A large number of algorithms are reported in literature for optimal placement of FACTS devices [7], [8], [9] & [10]. Gravitational search algorithm (GSA) based on Newton's law of gravity have been used for optimization of complex problems [11], [12] & [13].

Although provides superior results in most cases but is unable to provide solution in high and low dimensional space. The solution tends to confine to local optima. This limitation is overcome by modified gravitational search algorithm (MGSA) which provides better quality solutions with faster convergence.

III. Static Modeling of SSSC

SSSC is a series compensator using Gate Turn off (GTO) based voltage source inverter. It is capable of providing active and reactive power support. In reactive power support mode, it can regulate reactive voltage drop in line and can control power flow to ease congestion. The equivalent circuit used here uses series voltage injection model [14] as shown in fig. 1.

Figure 1 Equivalent circuit of SSSC



At bus i

$P_i = V^2_i\, G_{ii} – V_i\, V_j\, (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) – V_i\, V_{se}\, (G_{ij} \cos\theta_{ise} + B_{ij}\, \mathrm{Sin}\, \theta_{ise})$ (1)

$Q_i = V^2_i\, B_{ii} – V_i\, V_j\, (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) – V_i\, V_{se}\, (G_{ij} \sin\theta_{ise} - B_{ij} \cos\theta_{ise})$ (2)

At bus j

$P_j = V^2_j\, G_{jj} – V_i\, V_j\, (G_{ij} \cos\theta_{ji} + B_{ij} \sin\theta_{ji}) + V_j\, V_{se}\, (G_{ij} \cos\theta_{jse} + B_{ij}\, \mathrm{Sin}\, \theta_{jse})$ (3)

$Q_j = V^2_j\, B_{jj} – V_i\, V_j\, (G_{ij} \sin\theta_{ji} - B_{ij} \cos\theta_{ji}) + V_j\, V_{se}\, (G_{ij} \sin\theta_{jse} - B_{ij} \cos\theta_{jse})$ (4)

Where, $\theta_{ij} = \theta_i - \theta_j$, $\theta_{ji} = \theta_j - \theta_i$

$\theta_{ise} = \theta_i - \theta_{se}$, $\theta_{jse} = \theta_j - \theta_{se}$

G_{ii} & B_{ii} = Conductance and susceptance of bus i

G_{jj} & B_{jj} = Conductance and susceptance of bus j.

G_{ij} & B_{ij} = Conductance and susceptance of line i - j.

IV. Problem Formulation

This work is carried out with objective to optimally locate SSSC so that there is minimum real power loss, minimum voltage deviation and cost of investment of SSSC is minimum.

The objective function is described below-

$$\mathbf{F = Min\,[x_1 . S. C_{sssc} + x_2\, P_{Li} + x_3 . LVD]} \quad (5)$$

Where, C_{SSSC}= Investment cost of SSSC in US \$/kvar.

S = Operating range of SSSC in Mvar, P_{Li} = Real power loss of system,

LVD = Load bus voltage deviation, x_1, x_2, & x_3 = Weighting factors,

x_1= 0.50, $x_2 = x_3 = 0.25$

(i) Minimization of investment cost of SSSC

$$\mathbf{C_{SSSC} = 0.00039\, S^2 - 0.3245\, S + 173.42 \quad (US\$/kvar)} \quad (6)$$

(ii) Minimization of real power loss

$$\mathbf{P_{Li} = \Sigma_{NL}\, [V^2_i + V^2_j – 2\, V_i\, V_j \cos(\theta_i - \theta_j)]\, Yij \cos\phi ij} \quad (7)$$

Where, N_L= number of transmission lines in the system, Y_{ij} = admittance matrix, $V_i \angle\theta_i$, $V_j \angle\theta_j$ = sending end and receiving end voltages and angles, ϕ_i , ϕ_j, = angles of admittance of lines between buses i and j,

(iii) Minimization of load bus voltage deviation

Bus voltages are maintained within acceptable range. Voltage profiles of buses are improved by restricting deviation with respect to a set reference value that is 1.0p.u.

$$\boldsymbol{LVD = \sum_m [V_i - V_{ref}]} \quad (8)$$

Where, V_i = voltage of i^{th} bus, $V_{ref} = 1.0pu$.

V. Result and Discussion

The present work is coded in MATLAB 7.9 platform using 2.8 GHz Intel dual core processor PC. The work is tested on IEEE-57 bus system. Newton-Raphson method is used for loadflow.

Table – 1 shows voltage profile of buses in IEEE-57 bus system. This is depicted graphically in figures. Table -2 show the bus voltage profiles without SSSC and with SSSC using MGSA for the best fitness branches (8-9) and (9-11).

It is observed that voltage profile with SSSC in branch (8-9) using MGSA has improved compared to without SSSC. Similar result is obtained for branch (9-11). In both the cases, the effectiveness of SSSC in improvement of bus voltage using MGSA is demonstrated. It is observed that line losses are reduced in both the branches with the installation of SSSC. Since the cost of investment of SSSC is lower in branch (9-11) compared to branch (8-9), hence branch (9-11) is the optimal location of SSSC in IEEE-57 bus system.

VI. Conclusion

In this paper, optimal location of SSSC is presented for minimum cost of investment of SSSC, minimum power loss and minimum deviation of voltage of load buses using improved gravitational search algorithm (MGSA).

Conventional Gravitational Search Algorithm (GSA) was found to be superior to PSO (particle swarm optimization) and RGA (revised genetic algorithm) but the algorithm failed to converge when the search space increases exponentially. So, an improved version of GSA is tested here which provides optimal solution in large search space with faster convergence characteristics. It is seen that SSSC could improve the voltage profile. MGSA algorithm could find optimal location which satisfies three sub objectives.

It was found that location of SSSC in bus 9-11 satisfies all the three sub objectives. Hence, bus 9-11 is the optimal location for SSSC in IEEE-57 bus system.

Table 1: Comparison of voltage profile without and with SSSC using GSA and IGSA in IEEE-57 bus system

Bus voltage profile(pu)							
Best fitness branch(8-9)				**. Best fitness branch(9-11)**			
Bus no.	**Without SSSC**		**With SSSC using MGSA**	**Bus no.**	**Without SSSC**		**With SSSC using MGSA**
4	1.0401		1.0350	10	1.0703		1.0552
5	1.0383		1.0382	11	1.0564		1.0587
10	1.0703		1.0545	13	1.0620		1.0192
11	1.0564		1.0563	15	1.0548		1.0646
12	1.0651		1.0597	18	1.0922		1.0802
13	1.0621		1.0618	19	1.1259		1.0412
14	1.0643		1.0638	20	1.1364		1.1033
17	1.0598		1.0703	21	1.1928		1.0192
18	1.0922		1.0199	22	1.1931		1.1081
21	1.1928		1.0210	27	1.1196		1.0322
27	1.1196		1.0287	28	1.1032		1.0465
38	1.1907		1.0123	29	1.1032		1.0112
48	1.1924		1.0241	30	1.2520		1.0337
49	1.1933		1.0267	31	1.2736		1.0112
51	1.1611		1.0161	55	1.1046		1.0101
53	1.9392		1.0640	56	1.2070		1.0222
57	1.2182		1.0350	57	1.2182		1.0316

Table 2: Power loss and investment cost of SSSC in IEEE-57 bus system

FACTS devices used	**Installed location (branch)**	**Power loss(MW)**		**SSSC investment cost (US$/kvar)**
		Without SSSC	**With SSSC using MGSA**	
SSSC	**8-9**	**27.703**	**21.6954**	**29.7477**
	9-11	**22.711**	**21.2436**	**27.5723**

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