Optimal Placement Of Statcom Using Gravitational Search Algorithm For Enhanced Voltage Stability

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Abstract:-STATCOM is a FACTS device used for shunt compensation in transmission lines to maintain bus voltages within prescribed tolerance band. In this paper, a STATCOM is used to improve bus voltages and minimize transmission line losses by optimal placement in a standard power network. Gravitational Search Algorithm (GSA) has been tried to optimally place STATCOM by optimizing power losses and cost of STATCOM. The GSA generates good quality solutions achieves faster convergence.

Keywords: GSA; Optimal placement of STATCOM, Minimum power loss, Minimum installation cost,

1. Introduction

The last decade has seen transformation of monopolistic, vertically integrated electric utilities into deregulated market structure. Aim of deregulation was to improve service by introducing competition, increase revenue, and remove govt. control by leaving it to market forces. With the presence of large number of market players in deregulated structure and rising electricity demand have resulted in burdening of existing transmission infrastructure. With the result transmission systems are operating under severe overload creating congestion in select corridors.

The complexity of power system is increasing day by day due to system expansion, higher demand, loop flows, contract variety etc. Hence, to meet higher demand new generation sources and construction of new transmission lines are essential. But economic, environmental and geographic factors prevent construction of new transmission lines to ease congestion. The only solution available is to optimize the use of existing transmission lines. To realize this, FACTS or Flexible AC Transmission System is the solution. FACTS are power electronic based devices which can enhance voltage stability, security, stability margin, total transfer capability (TTC) etc. and can reduce losses, reduce cost of generation & remove congestion. However, FACTS are benefit. Also, if the device is not optimally placed, there may be negative impact on some market players in deregulated market and some specific case may affect system stability [1].

This paper uses gravitational search algorithm to find optimal location of STATCOM in a deregulated market. The criteria for optimal placement are-

(i) Installation cost of STATCOM &

(ii) Power losses. This is implemented on IEEE-14 bus system.

The paper is organized as follows: section-2 provides literature review. Modeling of STATCOM is given in section-3. Section-4 deals with application of GSA for optimal placement. This is followed by result and discussion in section-5 and conclusion in section-6.

2. Literature Review

In the literature, numerous classical and artificial intelligence based methods have been

described for optimal location of FACTS devices with varying objectives. All these methods can be broadly categorized into three classes viz (i) sensitivity based methods, (ii) optimization based methods and(iii) artificial intelligence based methods. Artificial intelligence based method are being used widely such as Genetic Algorithm (Tang et al 1996), Simulated Annealing (Kirkpatric et al 1983), Ant Search Algorithm (Dorigo et al 1996), Particle Swarm Optimization (Kennedy & Eberhart, 1995), Neutral Network (Hopefield, 1982), Tabu Search (Glover, 1989), Gravitational Search Algorithm (Rashidi et al, 2009) etc. These heuristic techniques employ one or more expensive devices and need to be utilized optimally so as to get maximum agents such as chromosomes /particles / neurons / ants etc. in a fixed number of iterations using competition co-operation principle for optimization [2].

Among classical methods, interior point method was used to minimize congestion and maximize social welfare to place UPFC (Unified Power Flow Controller) in a power network for expansion [3]. A Hybrid Evolutionary Algorithm was used to optimally place multi-type FACTS devices to maximize total transfer capacity [4].

The classical optimization methods such as linear programming, Lambda method & Gradient method assume convex nature of objective function. These methods cannot detect discontinuities in objective function and are trapped in local optima or simply fail to converge. Also, single simulation run provides only one optimum solution [5]. Hence artificial intelligence methods are fast, converge easily and provide global solution. Gravitational Search Algorithm is one such artificial intelligence based method that uses law of gravity and notion of mass interactions. This technique uses number of masses which attract each other by force of gravity and this force moves all other objects towards heavier mass. These heavier mass correspond to good solution. The mass is determined by using a fitness function [6].

Milanovic & Zhang [7] optimized the location of STATCOM based on installation cost for improvement of voltage sag. Siddiqui & Deb [8] used STATCOM & SVC to improve voltage stability in IEEE-14 bus system. An Improved Gravitational Search Algorithm

(IGSA) was used to find optimal location of UPFC by Siddiqui & Deb [9]. The criterion for optimal placement was minimum power loss. Nabavi et al [10] determined optimal location of SSSC (Static Synchronous Series Compensator) using genetic algorithm on IEEE-14 bus system. Sreejth, Psimon &Selevan [11] found optimal location of IPFC (Interline Power Flow Controller) using ABC algorithm.

3. Modeling of STATCOM

STATCOM is a shunt connected reactive power compensation FACTS device. It can also be used to regulate active power if batteries are provided.

It has faster rate of generation/ absorption of reactive power so as to maintain bus voltage. Generally, it consists of a coupling transformer, a voltage source inverter and a dc side capacitor. The single line diagram is given in figure 1 below-
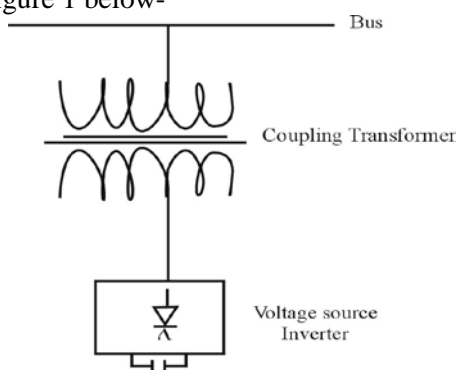

Fig. 1: Single diagram of STATCOM

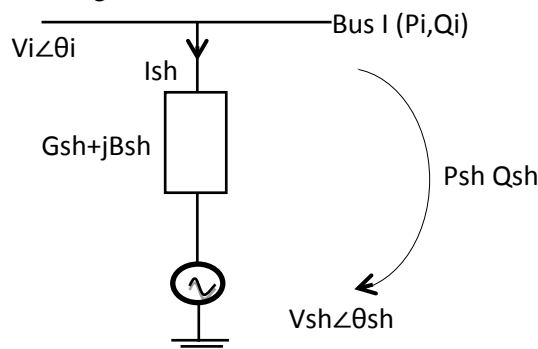The Equivalent circuit of STATCOM is shown below in figure 2

Fig.2 Equivalent circuit of STATCOM

The figure-2 shows bus voltage $Vi\angle\theta i$ and injected voltage Vsh θsh. After connection of

STATCOM to bus i, the power flow equations are given below-

$$P_i = P_{sh} + \sum_{j=1}^{N} V_i V_j V_{ij} \cos(\theta_{ij} - \delta_{ij}) \quad (1)$$

$$Q_i = Q_{sh} + V_i V_j V_{ij} \sin(\theta_{ij} - \delta_{ij}) \quad (2)$$

$$P_{sh} = G_{sh} V_i^2 - V_i V_{sh} Y_{sh} \cos(\theta_{ish} - \delta_{sh}) \ldots\ldots(3)$$

$$Q_{sh} = B_{sh} V_i^2 - V_i V_{sh} Y_{sh} \sin(\theta_{ish} - \delta_{sh}) \ldots\ldots(4)$$

Here, Pi and Qi are active and reactive power at bus I; Psh and Qsh are active and reactive power of STATCOM; N is number of buses connected to bus i; Y_{ij} is the admittance of line between bus i and j with angle δ_{ij}. Y_{sh}, G_{sh} and B_{sh} are admittance, conductance and susceptance of STATCOM respectively.

The optimal location of STATCOM is based on location of minimum power loss in the line and installation cost of STATCOM.

The cost function of STATCOM is given below [1]-

$$C_{STATCOM} = 553 [0.0004 C^2 - 0.3225C + 127.38] \text{ Pounds / MVAR where C is the capacity of STATCOM.}$$

4. Application of GSA for optimal placement

Gravitational Search Algorithm (GSA) is an optimization algorithm of recent origin (2009) based on law of gravity. This algorithm uses agents as objects and their performance is measured by their masses. All objects attract each other by force of gravity. This force causes global movement of objects towards heavier masses. These heavier masses correspond to good solution. So each mass presents a solution and algorithm is navigated by properly adjusting gravitational and inertia masses. With the passage of time, these masses are attracted by heaviest mass which represents optimum solution [6].

The various steps in the algorithm are following-

(i) Identification of search space.
(ii) Randomized initialization.
(iii) Fitness evaluation of agents.
(iv) Updation of G (t), best (t), worst (t) and M (t) for i =1, 2… N.
(v) Calculation of total force in different directions.
(vi) Calculation of acceleration & velocity.
(vii) Updation of agents' position.

(viii) Repetition of steps (iii) to (vii) till stop criteria is reached.
(ix) Stop.
Where, G (t) = Gravitational constant, best (t) and worst (t) are fitness values of agents.
Mi (t) = inertia mass of i th agent

5. Result & discussion

Table-1 shows voltage profile of IEEE-14 bus system with and without STATCOM. The optimal location based on minimum power loss and installation cost of STATCOM provides two solutions-(i) STATCOM to be installed between buses 1& 2 (ii) STATCOM to be installed between busses 1 & 5.

Table-1 Bus voltage without & with STATCOM using GSA

| Bus no.	Bus voltage without STATCOM (pu)	Best fitness buses 1& 2	Best fitness buses 1 & 5
		Bus voltage with STATCOM (pu)	Bus voltage with STATCOM (pu)
1	1.0600	1.0600	1.0600
2	1.0450	1.0450	1.0450
3	1.0100	1.0100	1.0100
4	1.0132	1.0143	1.0156
5	1.0166	1.0180	1.0202
6	1.0700	1.0700	1.0700
7	1.0457	1.0458	1.0465
8	1.0800	1.0800	1.0800
9	1.0305	1.0300	1.0309
10	1.0299	1.0294	1.0302
11	1.0461	1.0458	1.0462
12	1.0533	1.0533	1.0533
13	1.0466	1.0465	1.0466
14	1.0193	1.0189	1.0195
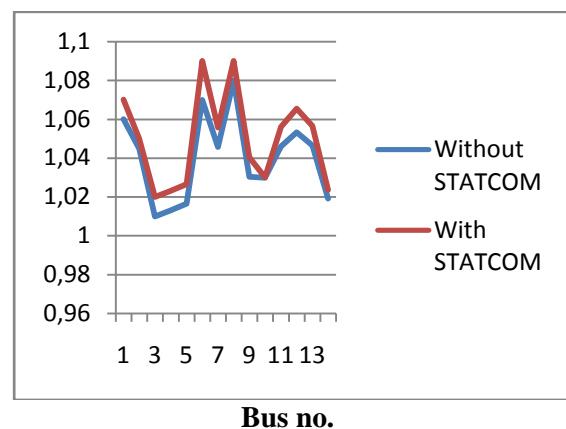
Bus no.
Figure 3: Voltage profile (pu) with & without STATCOM installed at bus 1-2
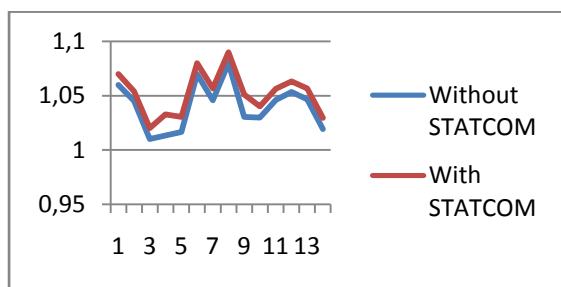
Bus no.
Figure 4: Voltage profile(pu) with &
without STATCOM installed at bus 1-5.

Figure 3 shows voltage profile of all buses without STATCOM (installed between buses 1-2) & with STATCOM. It is observed that voltage profiles of buses are improved with STATCOM (voltage tolerance band is 0.95 pu to 1.05 pu). Similarly, figure.4 shows voltage profile of all buses without and with STATCOM (optimally installed between buses 1-5). Here, again voltage profile is found to be improved.

Table 2: Comparison of power loss &
installation cost of STATCOM

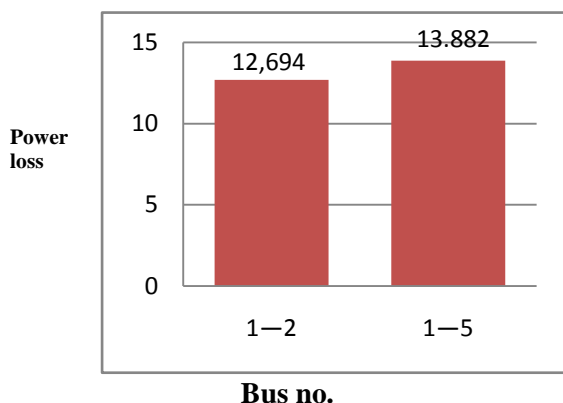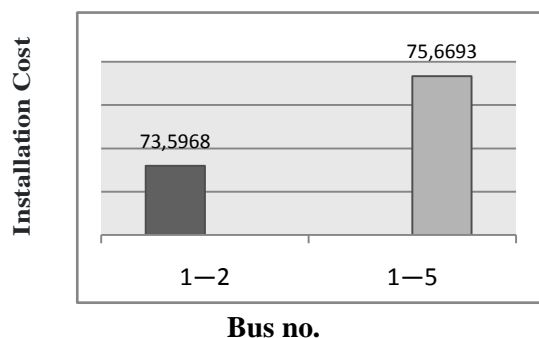| Optimal location (bus no.)	Power Loss (MW)		Installation cost (Pounds/MVAR)
	Without STATCOM	With STATCOM	
1-2	13.5929	12.6949	73.5968
1-5	15.2641	13.8828	75.6693

Figure: 5 Power loss with STATCOM at
buses 1-2 & 1-5.

Bus no.
Figure:6 Installation cost of STATCOM at
buses 1-2 & 1-5.

Table 2 shows that STATCOM reduces the power loss. The power loss and installation cost of STATCOM in bus 1-2 is less than in bus 1-5. This is depicted in figure 5&6.

6. Conclusion

Optimal location of STATCOM was determined using twin criteria of minimum power loss and minimum installation cost using gravitational search algorithm. The power loss and cost of installation of STATCOM is minimum at bus 1-2. Hence, bus 1-2 is optimal location of STATCOM .

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