Enhancing the Power System Loadability Using STATCOM Device

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Abstract- In the current power system much concentration is given to the efficient transmission of power from generator side to load end with minimum power loss. To achieve this, the newly introduced FACTS technology is being used. FACTS device such as STATCOM (static synchronous compensator) is used in this paper, for the efficient power transfer between transmission lines. To enhance the loadability of transmission lines an adaptive search algorithm called Improved Gravitational Search Algorithm (IGSA) is proposed. In the proposed approach the velocity of each agent is improved. If the agents' velocity is at maximum only then the optimum solution is obtained. In IGSA maximum power loss of the system is used as fitness function to improve the maximum power transfer capability. The proposed algorithm is implemented on IEEE 57 bus test system using MATLAB platform and the maximum power transferred is evaluated using STATCOM device. The results using IGSA are compared with traditional GSA.

Keywords- Agent, FACTS, Fitness function, IGSA, Loadability, Power transfer, STATCOM

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1 INTRODUCTION

The current power system is an electrical network consisting of various generators, transmission lines, variety of loads, various transformers etc. As the power system is rapidly expanding it is also becoming more and more complex. Some of the transmission lines get overloaded when a large amount of power is transferred suddenly. Moreover, installation of new transmission lines is restricted by some environmental and right of way (ROW) issues. Therefore the optimum utilization of the existing lines comes into play. Introducing various FACTS devices alleviate the problem of congestion. FACTS devices improve the power transfer by controlling the transmission line parameters such as terminal voltage, phase angle of bus voltages and line impedance. FACTS controllers such as SVC, TCSC, UPFC, IPFC, SSSC, STATCOM, TCPAR etc are used to enhance the power system loadability. These devices not only help in reducing congestion but also reduce system losses, improve system stability, reduce the SSR (sub synchronous resonance) problem and thus reducing the overall cost of power delivery.

In this paper improved gravitational search algorithm is introduced to enhance the maximum power transfer capability of power system using STATCOM device. In this approach velocity and position of agents are improved over the traditional GSA (gravitational search algorithm). The proposed approach reduces the computational complexity and has faster rate of convergence as compared to traditional GSA.

This paper is divided into various sections. Section 2 contains an overview of recent work done. Section 3 gives the mathematical modeling of STATCOM. Section 5 and 6 are about results and conclusion.

2 LITERATURE REVIEW

K.Vijaykumar et.al [1] have offered an alternate algorithm using a genetic algorithm to work out the optimal power flow problem integrating stretchy AC transmission system devices (FACTS) in a multi-machine power system. By using their proposed algorithm, they found out the location and ratings of TCSC and UPFC. To find out the optimal location of FACTS devices, the overall system cost is considered. The overall system cost includes generation cost and investment cost of FACTS devices.

G.Madhusudhana Rao et al. [2] have suggested a real code GA for optimizing the location and to control parameters of TCSC and SVC for accomplishing maximum available transfer capability (ATC). ATC was calculated using continuous power flow (CPF) technique. Both the line thermal limit and bus voltage limits were considered. The suggested real –code GA was experimented on IEEE-24 bus test system. The simulated results demonstrated that SVC improved voltage profile whereas TCSC enhanced ATC in both the thermal and voltage dominated case.

Suppakarn Chansareewittaya et al. [3] have offered evolutionary programming (EP), split and non split search space managing techniques for the optimally sitting and settings of FACTS devices. TCSC and SVC

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were used independently to maximize the power transfer capability and also minimizing power losses. This technique is implemented on IEEE-118 bus system and the practical electricity generating authority of Thailand (EGAT) 58 bus system. The simulated results showed that the split search space managing technique is better than non-split technique.

Battacharya et al. [4] have offered GSA for multi-objective optimal power flow problem. A normal 26-bus and IEEE 118 bus plans with three different individual objectives that are fuel cost minimization; active power loss minimization and voltage deviation minimization were calculated. In multi-objective problem formulation fuel cost and loss, fuel cost and voltage deviation, fuel cost, loss and voltage deviation were reduced at the same time. Their proposed technique results were assessed with a different integer particle swarm optimization, Evolutionary programming and genetic algorithm. The simulation results demonstrated the convergence, speed and global search capability.

Harinder Sawhney et al. [5] have made a proposal for deregulation in the electric power industry and creating opportunity for the market to liberate economic energy to the consumers. This generated novel challenges for the functioning of power system.

A few of these challenges could be met using flexible AC transmission system (FACTS) devices. A one kind of FACTS device moreover suggested was unified power flow controller (UPFC) to get an enhanced transfer capability of power system. Mohammad Khajehzadeh et al. [6] have suggested a flourishing modification of GSA. The approach used an adaptive maximum velocity restraint, which has superior global exploration capability than the original algorithm, has faster convergence rate and thus an acceptable solution is reached with a lower number of iterations.

Serhat Duman et al. [7] suggested a gravitational search algorithm (GSA) to find out the optimal solution for optimal power flow (OPF) problem. The proposed method was implemented on IEEE-30 and IEEE-57 bus test systems. The results confirmed that it is a quality technique for OPF problems.

3 MATHEMATICAL MODELLING

STATCOM is used to compensate the active and reactive power needed by the power system. It has the advantage of a faster rate of generating/absorbing reactive power. The main purpose of STATCOM is to inject or absorb reactive power to or from the bus to which it connected thus regulates the bus voltage magnitude. Generally, it consists of a coupling transformer, a voltage source inverter (VSI) and a source of storage like capacitor on the DC side. The single line circuit diagram of the STATCOM is illustrated in Fig. 1.

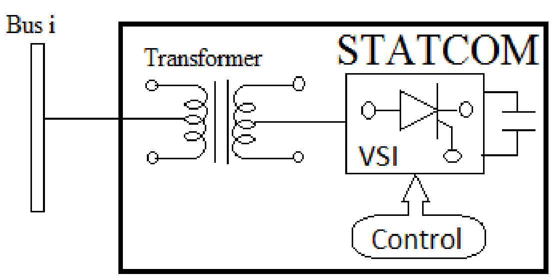

Fig. 1 Single line diagram of STATCOM connected to bus *i*

Here, STATCOM is connected to bus *i*. It is a shunt connected VSI through a shunt transformer which can absorb or inject reactive power by injecting shunt voltage. Its equivalent circuit model is shown in Fig. 2.

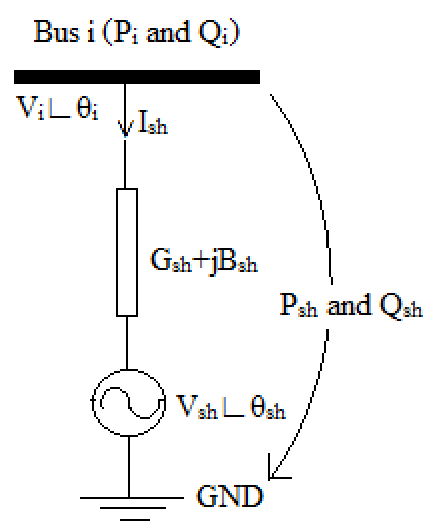

Fig. 2 Equivalent circuit model of STATCOM

In Fig. 2, an equivalent circuit model of the STATCOM is shown injecting shunt voltage. The injected shunt voltage and its phase angle is $V_{sh}\angle\theta_{sh}$. $V_i\angle\theta_i$ is the voltage and phase angle of bus i. After connecting STATCOM to bus *i*, the power flow equations of the system are as follows [8].

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

$$Q_i = Q_{sh} + \sum_{j=1}^{N} |V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_{ij}) \quad (2)$$

With

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

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

Where

P_i & Q_i and P_{sh} & Q_{sh} are the active & reactive powers at bus *i* and STATCOM. N is the number of buses connected to bus *i*, Y_{ij} is the admittance of the line between bus *i* and *j* with angle δ_{ij}. Y_{sh}, G_{sh} & B_{sh} are the admittance, conductance and susceptance of the STATCOM.

The cost function of the STATCOM is given as follows [9].

$$C_{STATCOM} = 0.0003S^2 - 0.3051S + 127.38$$

\$/KVAR (5)

Where,

S is the capacity of the STATCOM in MVAR.

Also,

$$S^{\min} \le S \le S^{\max}$$

Where,

$S^{\min}$ and $S^{\max}$ are the minimum and maximum values set for STATCOM capacity respectively.

The power transfer capability of network depends upon constraints such as voltage stability, active and reactive power flow and power loss which are described below.

3.1 Constraints

The following are the constraints associated with the power transfer capability of network.

3.1.1 Voltage Stability

Power transfer capability of network depends upon voltage stability of each bus. To improve power flow voltage of all buses should be in the range of 0.95 to 1.05 *p.u*. Voltage instability can be given by following equation.

$$\Delta V(m) = \frac{1}{\sqrt{l}}\sqrt{\sum_{m=1}^{l}\left(V_k^{\,m}\right)^2} \quad (6)$$

Where,

$$V_k^{\,m} = V_{slack} - \sum_{m=1}^{n} Z_E\left(\frac{P_m - jQ_m}{V_m}\right) \quad (7)$$

The bus voltage must lie within the following limits.

$V_m^{min} \le V_m \le V_m^{max}$.

Where V_m is the bus voltage, *m*= 1, 2, 3, 4….*n*, V_{slack} is slack bus voltage, ΔV_m is voltage stability index of bus *m*. P_m and Q_m are active and reactive power of bus m and l is the number of nodes.

3.1.2 Active and Reactive Power Flow

The following equations give active and reactive power flow.

$$P_m = V_m.V_n \sum_{n=1}^{N_B}\left(G_{mn}\cos\delta_{mn} + B_{mn}\sin\delta_{mn}\right) \quad (8)$$

$$Q_m = V_m.V_n \sum_{n=1}^{N_B}\left(G_{mn}\sin\delta_{mn} - B_{mn}\cos\delta_{mn}\right) \quad (9)$$

Here using the Newton-Raphson method, active and reactive power flow is determined. From the above equations N_B is total number of buses, G_{mn} and B_{mn} are conductance and susceptance respectively. δ_{mn} is the angle between m and n buses. V_m and V_n are voltages of buses m and n respectively.

3.1.3 Power Loss

Using the proposed approach, maximum power loss buses are selected. By using STATCOM in the network power loss is reduced. Power loss between buses m and n is given by following equation (without any FACTS device).

$$P_{mn} = \frac{V_m . V_n}{X_{mn}} \sin \delta_{mn} \tag{10}$$

δ_{mn} is angle between buses m and n and X_{mn} is the reactance between buses m and n.

The following equation describes power balance equation (11), which is an equality constraint.

$$\begin{pmatrix} S_m \\ S_n \\ \vdots \\ S_N \end{pmatrix} = \begin{pmatrix} P_{Gm} & + & jQ_{Gm} \\ P_{Gn} & + & jQ_{Gn} \\ \vdots & & \vdots \\ P_{GN} & + & jQ_{GN} \end{pmatrix} = \begin{pmatrix} (P_{Dm} + P_{Lm}) & + & j(Q_{Dm} + Q_{Lm}) \\ (P_{Dn} + P_{Ln}) & + & j(Q_{Dn} + Q_{Ln}) \\ \vdots & & \vdots \\ (P_{DN} + P_{LN}) & + & j(Q_{DN} + Q_{LN}) \end{pmatrix}$$

Power loss of bus m is given by following equations

$$P_{Lm} = |V_m . V_n| |Y_{mn}| \sum_{n=1}^{N} \cos(\alpha_{mn} - \delta_m - \delta_n) \tag{12}$$

$$Q_{Lm} = |V_m . V_n| |Y_{mn}| \sum_{n=1}^{N} \sin(\alpha_{mn} - \delta_m - \delta_n) \tag{13}$$

Here Y_{mn} is bus admittance matrix, δ_n and δ_m are load angle of bus n and m respectively, α_{mn} is angle between bus m and n. P_{Gm} and Q_{Gm} are active and reactive power generation. P_{Lm} and Q_{Lm} are active and reactive power loss. P_{Dm} and Q_{Dm} are active and reactive power demand.

4 PROPOSED APPROACH FOR MAXIMUM POWER TRANSFER CAPABILITY OF STATCOM

To solve the optimization problems with high dimensional search space, the classical optimization algorithms do not give a better solution because search space increases exponentially with the problem size. Hence to solve these problems using non-heuristic techniques is not practical. Researchers are finding great interest in algorithms based on the behavior of natural phenomena such as genetic algorithm, ant colony search algorithm, particle swarm optimization, Bee's algorithm etc. All these heuristic algorithms are meant for different problems. Furthermore, all the optimization problems cannot be solved by a particular heuristic optimization algorithm. Some algorithms provide better solution for specific problems than others. GSA (gravitational search algorithm) is a recent optimization algorithm based on Newton's law of gravity. But GSA doesn't provide a better solution to optimization problems with high and low dimensional search space. Whereas, the maximum power transfer capability of FACTS devices is associated to high and low dimensional search space. As a result, an improved version of GSA called IGSA (improved gravitational search algorithm) is proposed in this paper which gives a suitable solution to such optimization problems. In IGSA, velocity and position of agents are improved. Agents with a higher velocity move to an optimum solution. By the proposed approach, the solution is converged much faster when compared to traditional GSA.
Comparison between GSA and IGSA

GSA

1) Ascertaining a search area
2) Randomly initialized
3) Fitness evolution of agents
4) Upgrading *G(t)*, *best(t)*, *worst(t)* and *Mi(t)* for i=1,2,…..N
5) Computing local force acting in various directions
6) Calculation of acceleration and velocity
7) Update position of agent
8) Repeat steps (3)-(7) until stop criteria is achieved
9) End

IGSA
1) Ascertaining a search area

2) Randomly initialized
3) Fitness evolution of agents
4) Upgrading *G(t)*, *best(t)*, *worst(t)* and *Mi(t)* for *i*=1,2,….*N*
5) Calculation of acceleration and velocity
6) Update position of agent
7) Application of disruption operator
8) Repeat steps (3)-(7) until stop criteria is achieved
9) End

Where *G(t)* is gravitational constant, *Mi(t)* is inertia mass of i^{th} agent, *best(t)* and *worst(t)* are fitness values of agents.

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5 RESULTS AND DISCUSSIONS

The proposed approach is implemented on IEEE-57 bus system using MATLAB platform. N-R method is used to perform load flow analysis on the test system using equations 8 and 9.
Table 1 shows the voltage profile of IEEE-57 bus system with GSA and IGSA approaches. Voltage of each bus should lie between (0.9 to 1.1 *p.u.*). It is clear from the table that voltage at each bus is improved using IGSA as compared to GSA. Thus the table and figure clearly state that IGSA is better than GSA in improving voltage profile.
Here maximum power loss buses are 2-3 and 8-9. Bus voltages are affected by power loss. Therefore STATCOM is connected between fitness buses 2-3 and 8-9 to improve voltage profile.
The power loss of the system is given in table 2 using GSA and IGSA. After connecting STATCOM between fitness buses 2-3 and 8-9, the power loss of the system is calculated using GSA and IGSA. The results in the table confirm that IGSA reduces power loss as compared to GSA.
Table 3 gives the cost of STATCOM connected at fitness buses 2-3 and 8-9. The optimum location of STATCOM in the system depends upon the minimum cost of STATCOM.
Hence bus 8-9 can be the location for STATCOM installation which gives minimum cost.

TABLE 1
COMPARISON OF VOLTAGE PROFILE OF THE TEST SYSTEM

Voltage profile in pu					
Best fitness buses 2 and 3			Best fitness buses 8 and 9		
Bus no.	GSA	IGSA	Bus no.	GSA	IGSA
4	1.0399	1.035	10	1.0703	1.0546
7	1.044	1.040	12	1.065	1.0597
10	1.0703	1.0546	13	1.0618	1.0618
12	1.065	1.0597	19	1.1258	1.0921
14	1.0639	1.0639	20	1.1362	1.1033
18	1.0922	1.0898	22	1.1929	1.1158
20	1.1361	1.1034	23	1.1941	1.1197
21	1.1927	1.1045	25	1.2364	1.1258
24	1.2007	1.1237	26	1.1487	1.1284

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30	1.252	1.1487	33	1.2681	1.1718
31	1.2735	1.1489	34	1.2162	1.1834
32	1.2665	1.1611	36	1.2042	1.1905
34	1.2162	1.1835	37	1.2003	1.1921
39	1.2007	1.1927	39	1.2006	1.1926
40	1.2028	1.1929	40	1.2027	1.1929
50	1.1973	1.1115	51	1.1611	1.0162
52	1.1286	1.0135	54	1.1284	1.1052
56	1.2068	1.1682	57	1.2179	1.1135

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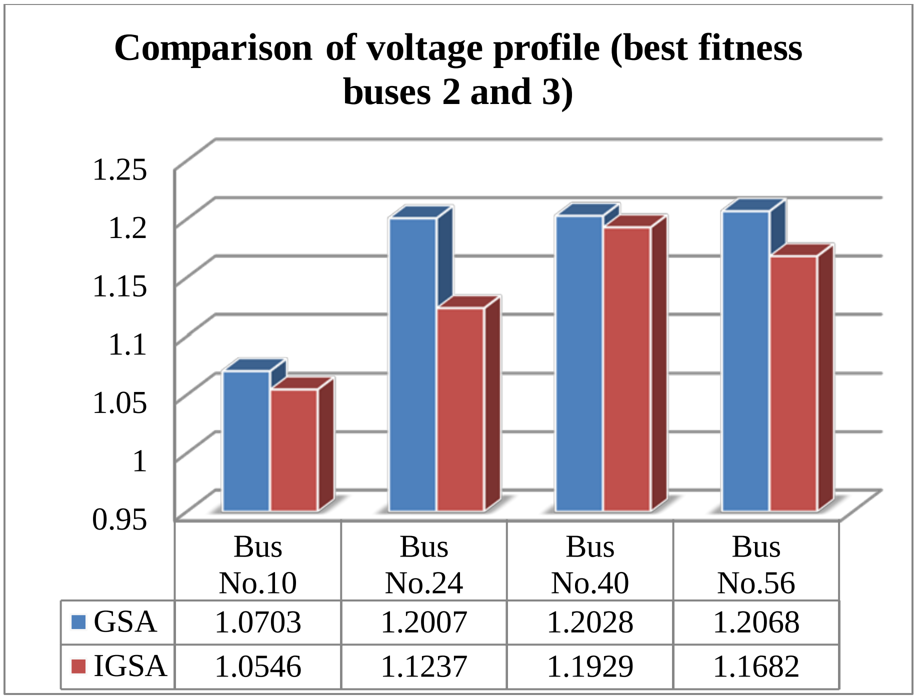

TABLE 2

POWER LOSS COMPARISON OF THE TESTING SYSTEM

Bus no		Maximum power transferred by STATCOM				Power loss after connecting the STATCOM	
		Bus 1 to 2		Bus 2 to 1		GSA	IGSA
From bus	To bus	Real power (P)	Reactive power (Q)	Real power (P)	Reactive power (Q)		
		MW	MVAR	MW	MVAR	MW	MW
2	3	87.921	41.082	90.516	33.681	22.703	20.6532
8	9	173.485	52.268	176.519	36.792	22.703	20.6532

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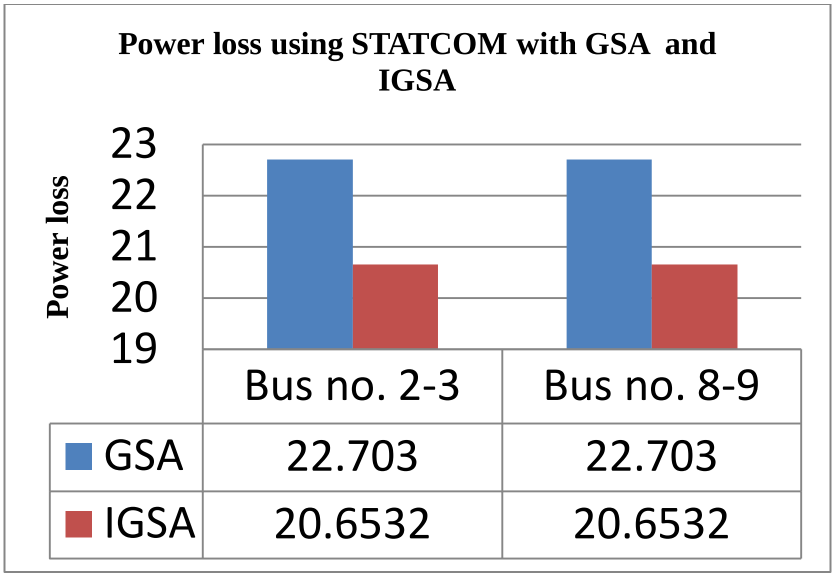
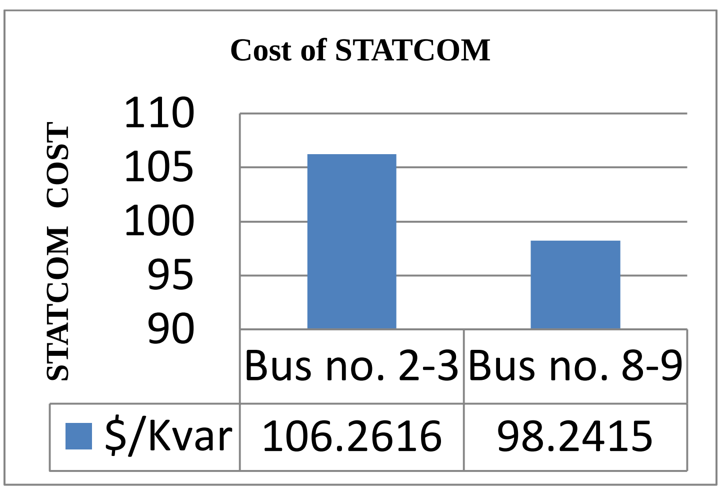


TABLE 3

COST OF STATCOM

From bus	To bus	STATCOM cost ($/KVAR)
2	3	106.2616
8	9	98.2415



6 CONCLUSIONS

In this paper, it is proposed that IGSA can improve the maximum power transfer capability in a power system using STATCOM device. The proposed approach reduces the computational complexity of the traditional GSA by improving velocity and position of agents. It is implemented on IEEE 57 bus test system. The performance of IGSA is compared with conventional GSA in terms of bus voltage profile and total power loss of the system. The optimum location of STATCOM is also found out based on the minimum cost of the device through IGSA technique. The results from the above tables confirm that the IGSA approach is superior to the conventional GSA.

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