

Optimal Location of STATCOM on Transmission Network using Evolutionary Algorithms

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ABSTRACT

This paper illustrates successful identification of optimal location of STATCOM (Static Synchronous Compensator) on various test transmission networks using evolutionary algorithms namely PSO (Particle Swarm Optimization), BFO (Bacterial Foraging Optimization) and Plant Growth Optimization techniques. STATCOM device is one of the shunt compensation devices available and is expected to improve the voltage profile significantly. However transmission losses also have to be kept in mind, in this paper objective function was taken as transmission loss minimization. By identifying the STATCOM location with minimum transmission loss in the network it is possible to have a network with healthy voltage profile and less transmission loss resulting increase in network efficiency. The results obtained by different evolutionary algorithms were found to be same, hence validating the results.

Keywords

Load flow analysis, PSO, BFO, Plant Growth Optimization, STATCOM.

1. INTRODUCTION

Transmission lines are often driven close to or even beyond their thermal limits in order to satisfy the increased electric power consumption and trades due to increase of the unplanned power exchanges. Due to this the bus voltage of load buses falls. This also leads to an increase in Transmission losses of the system. Thus to improve the overall voltage

profile we require shunt FACTS. STATCOM is one of the better shunt FACTS available [1].

STATCOM is a static synchronous generator that operates as a shunt connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.

Swarm Optimization techniques are derived from Darwin's Evolutionary Theory of 'Survival of fittest' [2-5]. In this paper we have used PSO, BFO and Plant Growth Optimization techniques for finding the optimal STATCOM location with

objective function as transmission losses. MATLAB is used for modeling and running the simulation.

However the papers approach solely doesn't rely on evolutionary techniques, as for the purpose of transmission loss

computations at various steps of algorithm Load flow analysis has to be done. Load flow computations have been done using MATPOWER 6.0 [6], which uses Newton Raphson method itself. This toolbox also helped in deciding the MVAr output of the STATCOM device being used.

For the purpose of testing a 5 bus [7], a 9 bus and a 30 bus system were used. Both 9 and 30 bus data are provided in MATPOWER 6.0 version [6].

This paper has been divided into 8 sections. 1st is the introduction. In 2nd section Transmission loss computation has been discussed followed by STATCOM modeling in 3rd section, which explains how to model STATCOM for usage in a MATLAB code. Next three sections explain the three algorithms been used. The next section discusses about the results obtained for different networks followed by the conclusion.

2. TRANSMISSION LOSS COMPUTATION

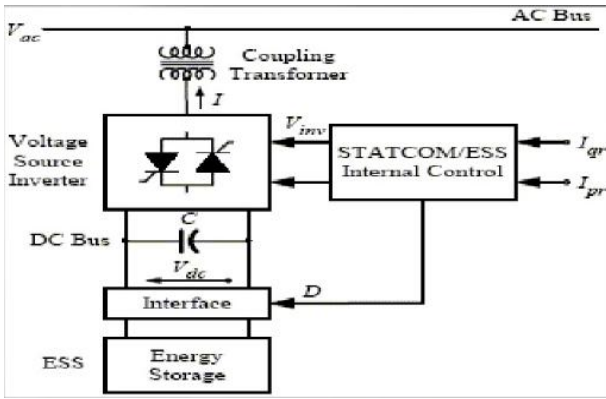
For Transmission Loss calculation, first load flow analysis has to be done on the network under consideration. With help of these losses of each branch is calculated as:

$$P_{\text{loss}}(\text{branch}) = P_{(\text{sending bus})} - P_{(\text{receiving bus})} \quad (1)$$

All the branch losses are summed up to get the total transmission loss of the network. This transmission loss is also the objective function of problem and has to be minimized.

3. STATCOM MODELING

STATCOM is a shunt compensation device which can be used for improving the voltage profile. It is a shunt controller and it injects current to the transmission line. System voltage is greater than generator voltage, it absorbs the reactive power and if smaller then it generates the reactive power. It can be based on both voltage source and current source convertor. It can be designed to be an active filter to absorb system harmonics.



STATCOM modeling was done as per suggestions in [7],[15-16]. STATCOM is always located on a load bus. The bus, on which STATCOM is being placed, is converted from PV bus to PQ bus. Thus STATCOM is considered as a synchronous generator whose real power output is zero and its voltage is set to 1 p.u.

4. PSO ALGORITHM

Particle Swarm Optimization is an evolutionary computation technique developed by Eberheart & Kennedy [8] in 1995 and is based on bird flocking and fish schooling. PSO is a stochastic technique as it makes few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. PSO has been proved to be one of the most promising algorithms for many intricate problems in engineering and sciences. Its simplicity and faster convergence make it an attractive algorithm to employ. The population is called swarm and the individuals are termed as particles. The word ‘swarm’ is inspired from jagged movement of particles in the problem region. The particles are assumed to be mass-less and volume-less [17].

4.1 Implementation

The dimension of the problem is determined by the number of load buses in the system, as only these are to be considered for STATCOM location. Then the current position of i^{th} particle can be represented by $P_i = [P_{i1}, P_{i2}, P_{i3}, \dots, P_{iN}]$ where P_i belongs to problem-space S . The particle flies with the current velocity given by $v = [v_{i1}, v_{i2}, \dots, v_{iN}]$ which is generated randomly in the range $[-v_{jmax}, v_{jmax}]$. The objective function values are calculated using (1) and are set as P_{best} values of the particles. The best value, based on individual fitness function is denoted by G_{best} or the global best value of swarm. New velocity for every dimension in each particle is updated as in (4):

$$v_{ij}^{t+1} = \text{ceil}(w * v_{ij} + c_1 * \text{rand} * (P_{best} - P_{ij}^t) + c_2 * \text{rand} * (G_{best} - P_{ij}^t)) \quad (4)$$

Where w is the weight vector whose value is to be suitably chosen, c_1 & c_2 are constants, rand is a uniformly distributed random value between [0 1], t represents iteration and P_{ij}^t is the

current position of the j^{th} dimension in the i^{th} particle. ‘Ceil’ function is used for making the value integral, as the updated bus no. has to be an integer. The new particle position is given by

$$P_{new} = P_{old} + v_{new} \quad (5)$$

When the stopping criteria are satisfied and there is no further improvement in the objective function, the position of the particles represented by G_{best} gives the optimal dispatch.

5. BFO ALGORITHM

The bacterial foraging optimization (BFO) algorithm is inspired from bio-mimicry of the e-coli bacteria and is a robust algorithm for non-gradient optimization solution, proposed in 2002 by

Kevin M Passino [9]. It consists of four steps: chemotaxis, swarming, reproduction & elimination-dispersal.

5.1 Implementation

The parameters initialized for run are: number of chemo-tactic steps (N_c), number of reproduction steps (N_{re}), number of elimination and dispersal steps (N_{ed}), dispersal probability (P_{ed}), number of bacteria (N) & swim length (N_s)[17]. An Ecoli can move in different ways: a ‘run’ shows movement in a particular direction whereas a ‘tumble’ denotes change in direction. A tumble is represented by:

$$\theta^i(j+1, k, l) = \theta^i(j, k, l) + v(i)\phi(j) \quad (7)$$

Where $\theta^i(j, k, l)$ represents i^{th} bacterium in j^{th} chemo-tactic, k^{th} reproductive, l^{th} elimination-dispersal step, $v(i)$ gives the step length and $\phi(j)$ is a unit length random direction given by

$$\phi(j) = \text{ceil}\left(\frac{\Delta(i)}{\sqrt{\Delta(i)^T * \Delta(i)}}\right) \quad (8)$$

Here again ceil is used to make the function integral helping in bus value updation.

At the end of specified chemo-tactic steps, the bacterium is evaluated and sorted in descending order of fitness. In the act of reproduction, the first half of bacteria is retained and duplicated while the other half is eliminated. Finally, bacteria are dispersed as per elimination and dispersal probability which helps hasten the process of optimization [10-11].

6. PLANT GROWTH ALGORITHM

This is a Bionic random algorithm [12]. According to the plant growth characteristics, an artificial plant growth model is built including leaf growth, branching, phototropism and spatial

occupancy. According to the growth law of plant higher is the morphactin concentration of a node, greater will be the probability to grow a new branch. The morphactin concentration is not fixed and is provided before. It's determined by the environmental features of the node.

6.1 Implementation

We in our approach used Plant growth algorithm with some modifications. We used the Morphactin concentration concept for fitness comparison purpose, while for particle updation we relied on the Bacterial foraging algorithms tumbling process. Morphactin concentration (C_{Mi}) is given by:

$$C_{mi} = (g(Bo) - g(Bmi)) / \Delta(i) \quad (9)$$

$$\text{Where, } \Delta(i) = \sum (g(Bo) - g(Bmi)) \quad (10)$$

$g(Y)$ is used for describing the environment of the node on a plant i.e. the Transmission loss of system on location of STATCOM at that particular system. $g(Bo)$ is the gbest, while $g(Bmi)$ denotes other nodes.

The node updating in this process takes place in a similar fashion as in bacterial foraging. The adjacent nodes morphactin concentration is checked. If it is found better, then it replaces current node from population set.

In each iteration best node is checked. If any node is found to have more morphactin concentration than previous gbest then it would replace the previous gbest value. In this fashion all possible growth nodes are checked, and best one is identified, one with highest morphactin concentration (fitness).

7. RESULTS AND GRAPH

Table 1. Demanded and generated power

Bus No.	Demand		Generated
	P(MW)	Q(MVar)	P(MW)
1*	0	0	0
2	20	10	40
3	60	10	0
4	45	15	0
5	40	05	0

Table 2. Bus data

From Bus	To Bus	R(p.u.)	X(p.u.)	B(p.u.)
1	2	0.02	0.06	0.06
1	4	0.08	0.24	0.24
2	4	0.06	0.18	0.18
2	3	0.04	0.12	0.12
2	5	0.06	0.18	0.18
4	5	0.01	0.03	0.03
4	3	0.08	0.24	0.24

Table 3.Data obtained from load flow analysis

Bus No.	Voltage		Generation		Load	
	Mag (p.u)	Ang (p.u.)	P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1.060	0	131.1	90.82	-	-
2	1.000	-2.06	40.0	-61.59	20.00	10.00
3	0.972	-5.76	-	-	60.00	10.00
4	0.987	-4.64	-	-	45.00	15.00
5	0.984	-4.96	-	-	40.00	5.00

The Total Transmission Loss=6.022 MW

Table 4. Transmission Losses for STATCOM on various Bus Locations

Bus Location	Total Transmission Loss
3	6.140
4	6.056
5	6.073

From table 4, it is evident that it is not possible to locate the compensator randomly on the transmission n/w just by considering bus voltage.

Hence, we need an iterative method or an evolutionary algorithm for finding out the optimal bus location for locating a STATCOM.

7.1 Results for 5-bus n/w with STATCOM

Optimal Bus Location is **bus 4**.

The MVAR rating of STATCOM is **20.47 MVAR**

The Voltage Profile improved.

Table 5.Data obtained after inclusion of STATCOM

Bus No.	Voltage		Generation		Load	
	Mag (p.u)	Ang (p.u.)	P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1.060	0	131.1	85.34	-	-
2	1.000	-2.05	40.0	-77.07	20.00	10.00
3	0.975	-5.79	-	-	60.00	10.00
4	1.000	-4.84	0.00	20.47	45.00	15.00
5	0.994	-5.11	-	-	40.00	5.00

The Total Transmission Loss=6.056MW

No. of Particles considered for calculation= 3

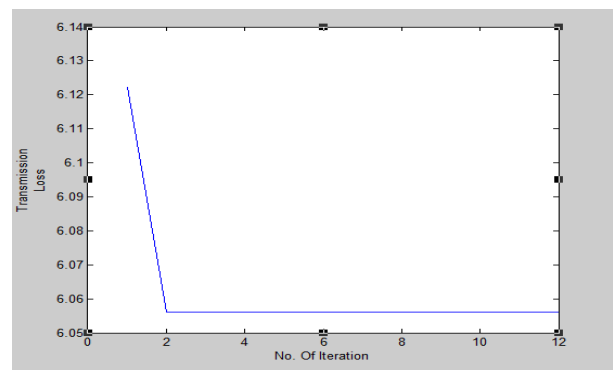


Fig1. Graph obtained for PSO Algorithm Implementation

No. of Bacteria Considered= 5

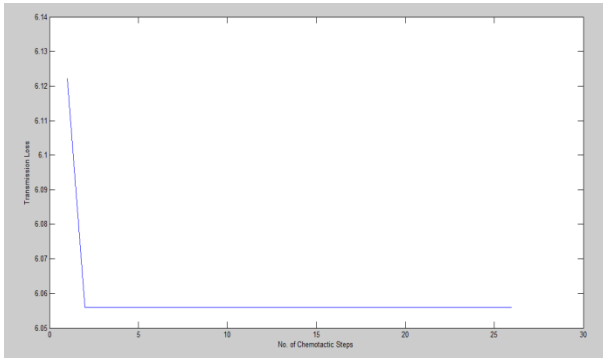


Fig2. Graph obtained for Bacterial Foraging Algorithm Implementation

No. of nodes taken in a set=1

No. of possible nodes =3

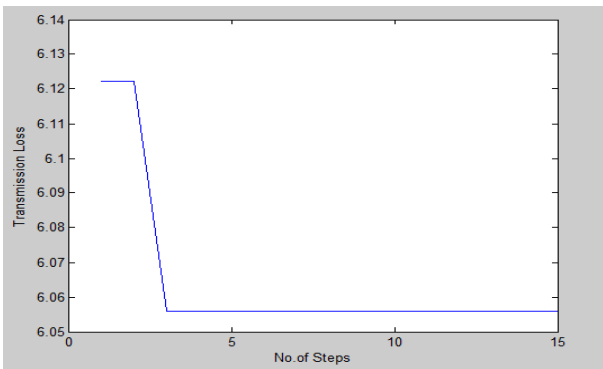


Fig3. Graph obtained for Plant Growth Algorithm Implementation

Table 6.9-bus Network Data

Bus No.	Demand		Generated
	P(MW)	Q(MVar)	P(MW)
1*	0	0	0
2	0	0	163
3	0	0	85
4	0	0	0
5	90	30	0
6	0	0	0
7	100	35	0
8	0	0	0
9	125	50	0

Table 7.Branch data of 9-bus

From Bus	To Bus	R(p.u.)	X(p.u.)	B(p.u.)
1	4	0.00	0.0576	0.00
4	5	0.017	0.092	0.158
5	6	0.039	0.17	0.358
3	6	0.00	0.0586	0.00
6	7	0.0119	0.1008	0.209
7	8	0.0085	0.072	0.149
8	2	0.00	0.0625	0.00
8	9	0.0032	0.161	0.306
9	4	0.001	0.085	0.176

Table 8.Data obtained from load flow analysis

Bus No.	Voltage		Generation		Load	
	Mag (p.u.)	Ang (p.u.)	P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1.000	0	71.95	24.07	-	-
2	1.000	9.67	163.0	14.46	-	-
3	1.000	4.77	85.0	-3.65	-	-
4	0.987	-2.41	-	-	-	-
5	0.975	-4.02	-	-	90.00	30.00
6	1.000	1.93	-	-	-	-
7	0.986	0.62	-	-	100.0	35.00
8	0.996	3.79	-	-	-	-
9	0.958	-4.35	-	-	125.0	50.00

The Total Transmission Loss=4.955MW

7.2 Results for 9-bus n/w with STATCOM

Optimal Bus Location is bus 9.

The MVar rating of STATCOM is 46.67 MVar .

The Voltage Profile Improved.

Table 9.Data obtained with STATCOM

Bus No.	Voltage		Generation		Load	
	Mag (p.u.)	Ang (p.u.)	P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1.000	0	71.95	24.07	-	-
2	1.000	9.573	163.0	14.46	-	-
3	1.000	4.837	85.0	-3.65	-	-
4	1.003	-2.36	-	-	-	-
5	0.988	-3.90	-	-	90.00	30.00
6	1.008	2.00	-	-	-	-
7	0.994	0.67	-	-	100.0	35.00
8	1.007	3.76	-	-	-	-
9	1.000	-4.34	0.00	46.77	125.0	50.00

The Transmission Loss=4.733MW

No. of Particles considered for calculation= 3

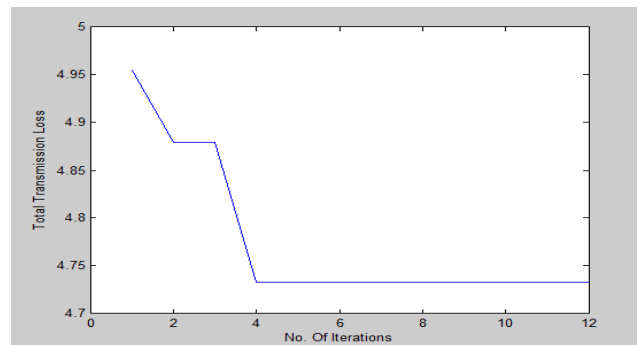


Fig4. Graph obtained for PSO Algorithm Implementation

No. of Bacteria Considered= 5

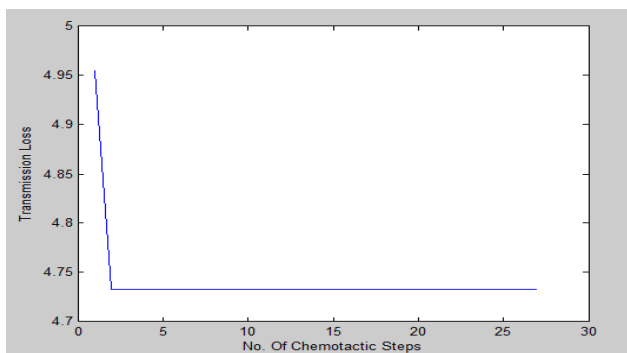


Fig5. Graph obtained for Bacterial Foraging Algorithm Implementation

No. of nodes taken in a set=1
 No. of possible nodes =3

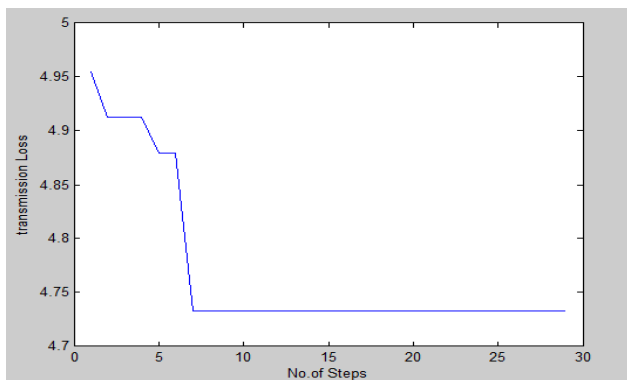


Fig6. Graph obtained for Plant Growth Algorithm Implementation

7.3 Results for 30-bus n/w system

The network data was taken from [4].
 The load flow output hasn't been included in this paper due to space constraints. However the overall voltage profile was found to improve on STATCOM inclusion, when compared to uncompensated system.

Table 10. Summarized data

System	30 bus
Optimal STATCOM Location	Bus 8
Optimal STATCOM Size	50.07 MVar
Transmission Loss of Uncompensated system	2.896MW
Transmission Loss of system with STATCOM	2.577MW

No. of Particles considered for calculation= 10

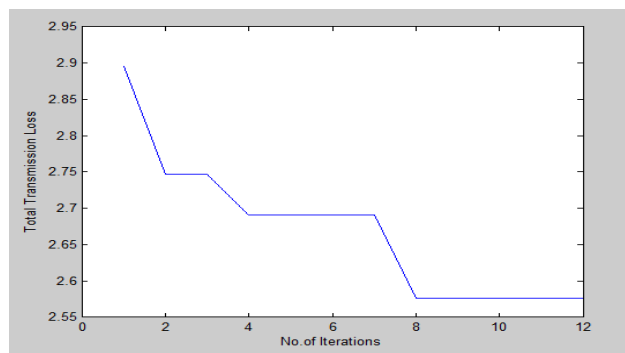


Fig7. Graph obtained for PSO Algorithm Implementation

No. of Bacteria Considered= 5

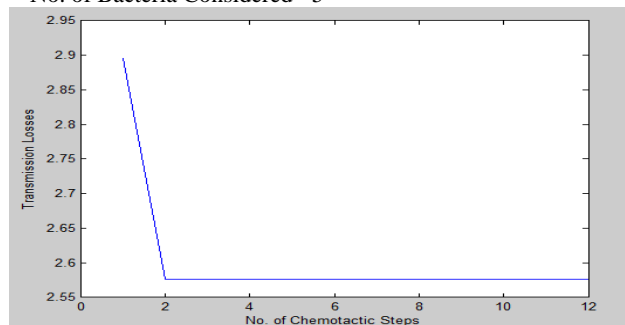


Fig8. Graph obtained for Bacterial Foraging Algorithm Implementation

No. of nodes taken in a set=5
 No. of possible nodes =24

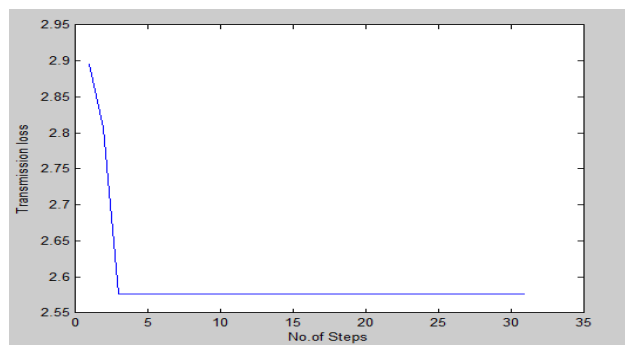


Fig9. Graph obtained for Plant Growth Algorithm Implementation

8. CONCLUSION

With the above work we can find the optimal location and size of STATCOM to be used in a transmission network. With the above results it can be seen that STATCOM is a very suitable device for voltage profile improvement and on proper location it can also help in bringing down the transmission losses of the system, thus improving the overall efficiency of the network. The method suggested is quite simple and could be favorably used to find the most suitable location.

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