A Multi-objective Optimization Approach for Optimal Location and Sizing of SVC to Enhance Power System Security

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Abstract — *The increase in power demand has made operation and planning of large interconnected power system more complex and therefore less secure than before. Hence, the modern power systems are more prone to widespread failures. One family of the device which can enhance the safe and reliable operation of the network and has contributed to the capacity augmentation is FACTS. But, they are very expensive and must be suitably sized and located to maximize the overall benefit to the system. This work aims to identify the optimal location and size of the Static Var Compensator (SVC) by optimizing the multi-objective function, formulated by different factors that define system security, namely Voltage Deviation, System Overload and Real Power Losses. The multi objective optimization function has been optimized using a Modified Bacterial Foraging Optimization Algorithm (MBFOA). The results are presented and analyzed for an IEEE 30 bus test system and Indian Utility Neyveli Thermal Power Station (IU-NTPS) 23 bus practical system.*

Keyword — *FACTS, SVC, System security, MBFOA, IEEE 30 Bus system, IU-NTPS.*

1. INTRODUCTION

A Flexible AC transmission systems (FACTS), a power electronics based device which was introduced in 1980s., It is now used as an economical and efficient means to control power transfer in an interconnected AC transmission system [1, 2].Over years, the use of FACTS controllers in transmission system have become crucial, to increase the system's capabilities by better utilization of existing power networks. In the conventional power system, there is very little or no control over the variables such as phase angles, bus voltages and line impedances. These variables control power flow and a change in any of them can change the power flow. A FACTS controller controls these variables, and hence the power flow gets controlled indirectly. Due to this, they provide a better stability of power system network, like voltage stability, line stability, small signal stability, transient stability, enhance power transfer capability. This in turn improves the system reliability. However, in all this the main role played using FACTS devices leads for controlling the power flow [3, 4]. Placing FACTS at proper location in a transmission system can result in control of line flow and maintenance of bus voltage level at the desired level. This leads to improvement in voltage stability margin. It is this compensating capability of FACTS devices that helps in reducing the flow of heavily loaded lines and thus maintains voltages at desired level. The only problem with the FACTS device is its cost. Therefore, it is important that it can be placed

at an optimum location, so as to get the nest results regarding the improvement of voltage stability margin and network security. The FACTS devices have been studied to know its effect on power system security, reliability and load ability, in accordance with proper control objectives [5-10].Various techniques have been discussed in various papers to find the optimal location for FACTS devices to enhance power system security and load ability. Proper allocation of FACTS devices have been presented to provide optimal results [5-15]. As such the optimization of location of FACTS device can be considered as a combinational optimization problem. Review of literature points to different heuristic and Meta heuristic approaches. It has been widely used to obtain an acceptable solution with limited computational time. Some of the approaches like Particle Swam Optimization (PSO) [16], Ant Colony Optimization (ACO) [17], Genetic Algorithm (GA) [18], Differential Evaluation (DE) [19] and Bacterial Foraging Optimization (BFOA) [20] have been used for solving this combinatorial optimization. H Sekhar et.al [21] proposed evolutionary optimization techniques to minimize the active power losses and enhance the voltage profiles in the power network. The techniques used are: general algorithm (GA), Particle Swarm Optimization (PSO) and Dragonfly Algorithm (DA). Recent works in regard to the optimal location of FACTS are presented here, N. Archana et.al. [22] proposed a modified bee colony algorithm, to find the optimal location of the FACTS devices: the STATCOM and the UPFC. This algorithm is also used to choose an optimal size of these FACTS devices. I.G Adebayo et.al.[23] proposed Network Structural Characteristics Participation factor (NSCPF) which makes use of the critical mode of power system and the Eigen vectors associated with it, to find the optimal location and size of the TCSC and UPFC type FACTS devices. A. N Zeinhom [24] studied the UPFC for a real 38 kV, 400km double circuit tie transmission line. The Genetic Algorithm (GA) optimization technique is used to formulate the optimal location and size of UPFC in MATLAB/SIMULINK. A.S Telang et.al [25] presented a systematic approach to find the optimal location of STATCOM on the power network along with its optimal size. The tangent vector method was used to calculate the voltage stability of the power network with and without STATCOM with the help of MATLAB. P. Kulkarni et.al. [26] has proposed methods to find the optimal location and size of the TCSC FACTS device, which would improve the power transfer capability of a transmission system. Sheath et. al. [27] used Particle Swarm Optimization (PSO) and PSO with time varying acceleration coefficient (PSO-TVAC), techniques to find optimal allocation and rating of a TCSC. PSO. S. Dixit et. al. [28] provided an overview of importance of optimal allocation of TCSC to enhance the

power system stability. The optimization techniques used for the same are: Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and some other heuristic techniques. The BFOA proposed by Kevin Paso in the year 2002 has attracted many researchers towards it. This can be attributed toward its less computational time, ability to provide global convergence and capability to handle more number of objective functions when compared with other evolutionary algorithms. In specific relation to its advantage for the power system is its immunity towards the size and non-linearity of the problem. Its performance remains unaffected by the size and non-linearity, a problem like optimal location of FACTS devices can offer. It also has the ability to provide convergence where most of the analytical methods have failed. Most of the existing works employ conventional BFOA and locate the FACTS device. Any suitable modification and improvements in BFOA can enhance its ability to find the global solution. The very structure of BFOA provides an opportunity in optimizing the tumble directions of the bacteria so that it can be guided effectively towards the global best of the population. Similarly, there is also a chance to dynamically alter the chemo tactic steps resulting in wider chance of individuals in reproduction view. This works aims at exploiting these two possibilities in delivering the Modified Bacterial Foraging Optimization Algorithm (MBFOA) and use it for the optimal location and sizing of Static VAr Compensator (SVC). The placement is optimized using a Multi Objective Function to identify the optimal location of SVC device and this function represents voltage deviation, system overload and real power loss. The proposed method is validated using IEEE 30 bus system. The (IU-NTPS) 23 bus practical system (Indian Utility Neyveli Thermal Power Station) results were obtained for validating the superiority of the proposed technique.

2. MODEL OF STATIC VAR COMPENSATOR (SVC)

This work aims at exploiting these two possibilities in delivering the Modified Bacterial Foraging Optimization Algorithm (MBFOA) [13, 14, 15] and use it for the sizing and optimal location Static VAR Compensator (SVC). The SVC has salient features like voltage stability, damping of power oscillations and maintaining the voltage constant at the desired value. This work aims at exploiting these two possibilities in delivering the Modified Bacterial Foraging Optimization Algorithm (MBFOA) [33-38] and use it for the sizing and optimal location Static VAr Compensator (SVC). The SVC has salient features like voltage stability, damping of power oscillations and maintaining the voltage constant at the desired value. The equivalent circuit of the variable susceptance model is shown in Figure 1 [26].
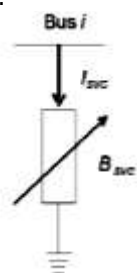

Figure 1 Variable susecptance model of SVC

The liberalized equation representing the total susceptance B_{svc} as state variable is given by the following equation

$$\begin{bmatrix} \Delta P_i \\ \Delta Q_i \end{bmatrix}^k = \begin{bmatrix} 0 & 0 \\ 0 & \frac{\partial Q_i}{\partial B_{svc}} \end{bmatrix}^k \begin{bmatrix} \Delta \theta_i \\ \Delta B_{svc} \end{bmatrix}^k \quad (1)$$

At each iteration (k), the variable shunt susceptance B_{svc} is updated

$$B_{svc}^{k+1} = B_{svc}^k + \Delta B_{svc}^k \quad (2)$$

Based on the equivalent circuit of SVC, the current drawn by SVC is

$$I_{SVC} = jB_{SVC}V_i \quad (3)$$

Reactive power drawn by SVC, which is also reactive power injected, Q_{svc} at bus i, is

$$Q_{SVC} = QB_{SVC} \quad (4)$$

3. PROBLEM FORMULATION

Multi-objective combinatorial optimization problems explore a finite search space for optimum and feasible solutions. These solutions should be optimum and often balance multiple objectives simultaneously. This is the fundamental challenge in different domains of engineering. Most of the multi objective problems are NP (Non deterministic Polynomial) time hard problems. To solve these problems, the approximation approaches that primarily depend on met heuristic have been used over a period of time. It is important that has to be kept in mind while using these met heuristic approaches is that they often identified only near optimal solutions and also suffer from parameters sensitivity. This value refers to the fact that the accuracy of the result is often influenced by the parameter setting of these approaches. In this research work one such optimization formulation has been employed. The primary goal of this formulation is to determine the optimal location and sizing of FACTS devices in a power system to enhance its security while keeping the system loses low. The proposed multi optimization problem is the representative of three different functions, namely Voltage Deviation, System Overload and Real Power Losses. The multi-objective function is represented as

$$MinF(x) = \lfloor F_V(x), F_S(x), F_{PL}(x) \rfloor \quad (5)$$

Subject to

$$x \in \Omega, Cj(x) = 0, j = 1......n, Hk(x) = 0, k = 1...p$$

Where, *F* and *x* are the objectives and decision vectors, Ω are the solution domain.

The notation Cj(x) is equality constraint and $H_k(x)$ is an inequality constraint. Various objective functions like $F_V(x)$, $F_S(x)$, and $F_{PL}(x)$ represents the voltage deviation, the system over load, and real power losses.

$$F_v = \sum_i |V_i - V_i^{ref}|^2 \quad (6)$$

$$F_s = \sum_j \left(\frac{S_j}{S_j^{max}}\right)^2 \quad (7)$$

$$F_{PL} = \sum_i P_{Li} \quad (8)$$

Where, V_i^{ref} is Nominal voltage magnitude (1 *pu* for all load buses),Vi is the voltage magnitude for i_{th} load bus, *Sj* is the apparent power for j_{th} line and S_j^{max} denoted as the max apparent power for j_{th} line. Finally, the real power at i_{th} line is represented as *PLi*. The proposed multi-objective function has to be optimized within certain constraints. These constraints can be very broadly classified into equality and inequality constraints. In this research work, the equality constraints load flow equations considered for real and reactive power flow conditions and the inequality constraints for the generation of reactive power constraints and the constraints for the FACTS device. The equality and inequality constraints are also considered to evaluate Modified BFOA. These constraints are listed below:

3.1. Equality constraints

These constraints represent the load flow equations corresponding to both real and reactive power balance equations, which can be written as:

$$PG_i - PD_i - \sum_{j=1}^{N} V_j \left[G_{ij} Cos(\theta_{ij}) + B_{ij} Sin(\theta_{ij}) \right] = 0 \qquad (9)$$

$$QG_i - QD_i - \sum_{j=1}^{N} V_j \left[G_{ij} Sin(\theta_{ij}) - B_{ij} Cos(\theta_{ij}) \right] = 0 \qquad (10)$$

Where:
PGi and *QGi*: generator real and reactive power at i^{th} bus respectively;
PDi and *QDi*: load real and reactive power at i^{th} bus respectively;
Gij and *Bij:* transfer conductance and susceptance between buses *i* and *j*, respectively.

3.2. Inequality constraints

Generation reactive power constraints:

$$Q_{Gi}^{\min} \langle Q_{Gi} \langle Q_{Gi}^{\max} \ for \ i = I \ldots N \qquad (11)$$

FACTS constraints:

For SVC $\quad Q_C^{\min} \langle Q_{SVC} \langle Q_C^{\max} \qquad (12)$

4. MODIFIED BACTERIAL FORAGING OPTIMIZATION ALGORITHM (MBFOA)

BFOA was initiated by Kevin Passino in the year 2002 [9]. He motivated by the social foraging behavior of E. coli bacteria and presented the BFOA. This algorithm has several advantages like the ability to achieve global optimization, insensitivity to initial values and ability to have parallel distributed processing. Through the reproduction operation it satisfies the rule of evolution which implies the survival of fitness. The usage of elimination dispersal procedure is used to nullify the premature convergence. The bacteria generated movement in the presence of chemical attractants and repellents is referred as chemo taxis for each bacterium [10, 20]. This process can be simulated by two distinct moves known as run or tumble. Throughout its entire lifetime, the bacteria alternate between these two modes of operation [33]-[38]. The alteration between these two moves helps the bacteria in its search for nutrients. In the case of bacteria the reproduction step happens. During this process, elimination and dispersal occurs so

that a bacterium in a particular region is dispersed because of a particular influence. This process of elimination and dispersal can affect the chemo tactic process and also assist it. In this proposed work, our modified BFOA is employed [33-38]. The bacterium representing a potential solution can be denoted by $\theta_{(j, G)}$, where '*j*' denotes the chemotaxic loop index while 'G' denotes the generation cycle loop index. This generational loop can be considered as a cycle in which processes are carried out. In addition to this, a swarming process is included in chemo taxis operation. The modified BFOA includes an attracter movement within the chemo taxis process. For the remaining steps the tumble - swim movement is used. In addition to this, an additional swim operator is also used making the total number of swim operators to two. The two new swims are also applied within the chemo taxis process. The first operator aims to compliment the swarming operator by letting bacteria explore other areas of search space by following randomly chosen bacteria. The second operator focuses on small movements of the bacterium in its vicinity having tiny step sized values [33-38].

Step 1: Different BFOA parameters are initialized.
Step 2: The fitness of the objective function is evaluated.
Step 3: The chemo tactic tumble or run is then initiated.
Step 4: The end of chemo tactic function is checked for stopping criteria. If yes, the operation is shifted to the next step or it returns back to step 2.
Step 5: The process of reproduction is initiated.
Step 6: The process of reproduction is checked for stopping criteria. If the condition is satisfied the operation moves to step 7 or else it moves to step 2.
Step 7: The process of elimination and dispersion is initiated.
Step 8: The elimination and dispersion process is checked for its stopping criteria. If the condition is satisfied the operation moves to step 9 or else it moves to step 2.
Step 9: The optimized solution is provided.

Reproduction and Elimination Dispersal are the next following processes to follow. The initial swarm of bacteria a skew operator is applied. This skew helps in the random generation of bacteria but with their location skewed to a particular area. The skew factor is applied randomly. Also to avoid the premature convergence of the bacterium, the reproduction step occurs only at certain cycles of the algorithm. This repetition cycle is predefined by a parameter assigned to it.

5. RESULTS AND DISCUSSION

The simulated results are coded using Mat lab Version 7.1 and MatPower version 5. The practical results at Neyveli Thermal Power Station (IU-NTPS) based on Modified BFOA are compared with IEEE 30 Bus System. For validating the proposed approach three test cases are considered, these scenarios can be envisaged as;
Scenario 1: This is the base case with normal load in all load condition; the load flow is carried out with a load factor of 1 across all the buses.
Scenario 2: This is a critical case in which a uniform load increase of 50% is considered across all the buses.

Scenario 3: This scenario is for checking the contingency response by considering the most critical line outage in the system.

5.1. IEEE 30 Bus test system

An IEEE 30 [31] bus system is considered to estimate and validate the proposed Modified BFOA technique. The standard IEEE-30 bus system has 6 generator buses and having the tap setting transformers.

Table (1) Results of base case before optimization

VMM	VMM	VAM	VAM	MPL (MW)	MQL (MW)
0.995 p.u.@ bus 30	1.058 p.u. @ bus 11	-17.81 Deg @ bus 30	0.00 deg @ bus 1	5.23 MW@ line 1-2	15.66 MVAr@ line 1-2
VMM=Voltage Magnitude Minimum VAM= Voltage Angle Minimum MPL= Maximum P Losses MQL= Voltage Angle Minimum MPL= Maximum Q Losses					

The assumptions are as follows. The upper limit is 1.05 p.u. for all the PQ buses and the reference bus [13, 14, 15]. In this work, the reactive load is 126.20 MVAr. The active load is 283 MW and the system's total generation capacity is 900 MW. The line number 5 is considered for analysis. Now, the results for base case before optimization in Table (1) and real and reactive power losses are given in the Table (2). The results of our earlier work have been considered to compare the results obtained for GA. The base case before optimization results are incorporated the Table (1). The real and reactive power losses can be observed in the Table (2).

Table (2) Real and reactive power losses for the base case before optimization

Total Active Power Loss (MW)	17.810
Total Reactive Power Loss (MVAr)	69.63

The results of optimal location and sizing of SVC for all the three scenarios are listed using the table (3) and for this placement the real power losses are calculated and tabulated using the table (4).

Table (3) Optimal location and size of SVC optimized by the proposed approach--Case 1

Operating Condition	Location of SVC- Bus	Size of SVC (MVAR)
Scenario 1	21	6.7325
Scenario 2	14	8.5468
Scenario 3	16	7.1002

Table (4) Comparison of real power loss before and after placement of SVC--Case 1

Operating Condition	Real Power loss Before SVC placement (MW)	Real Power loss after placement of SVC (MW)
Scenario 1	17.81	14.12
Scenario 2	46.90	44.01
Scenario 3	32.48	27.93

The percentage reduction in real power loss after placement of optimized size of SVC in locations identified by the algorithm is depicted using the figure (2).
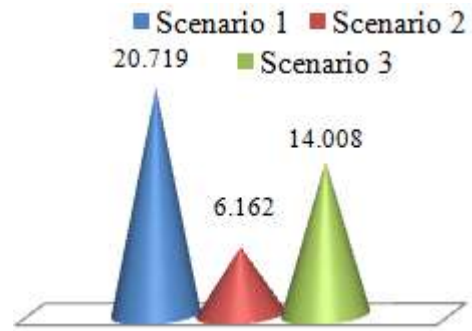

Figure 2 Plot of percentage reduction in real power loss post SVC placement for different scenarios --Case 1

There is appreciable improvement in real power losses on account of placement of SVC. For scenario 1, which is the base case the algorithm identifies bus 21 as the optimum location and suggests a size of SVC to be 6.7325 MVAR.

Table (5) Minimum voltage profile for different scenarios--Case 1

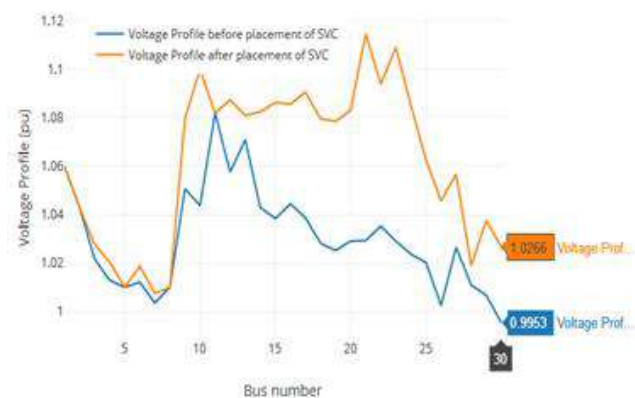| Operating Condition	MVO at Bus number	VPBP of SVC (p.u.)	VPAP of SVC (p.u.)
Scenario 1	30	0.995	1.026
Scenario 2	30	0.891	0.948
Scenario 3	7	0.972	0.985
MVO= Minimum Voltage Occurring VPBP= Voltage Profile Before Placement VPAP=Voltage Profile After Placement			

Figure 3 Voltage profile before and after placement of SVC for Scenario 1 -Case 1

This placement results in real power losses getting reduced by 3.69 MW, which translates to a reduction of 20.72 %. Similarly for scenario 2, the optimum size is identified to be 8. 5468 MVR placed at bus number 14. Such a placement results in reduction of real power losses from 46.90 MW to 44.01 MW. This amounts to 6.16 % reduction in real power loss. Similarly when the critical line outage of line 5 is considered for location of SVC placement, the optimum bus is identified to be bus number 16 and the size is fixed at 7.1002 MVAR. As inferred from the figure (4), this placement reduces the real power loss by 14.00 %. Similarly the enhancement

in voltage profile is tabulated through table (5) for different scenarios. Figure (3) provides a comparative plot of voltage profiles at different buses before and after placement of SVC. A visible improvement in voltage profile is observed across all the buses for scenario1. Similarly, the average loads bus voltage before and after the optimal location of SVC is tabulated in the table (6).

Table (6) Average load bus voltage before optimization and after optimized location of SVC- Case 1

Operating Condition	Average load bus voltage before placement of SVC (p.u)	Average load bus voltage after placement of SVC (p.u.)
Scenario 1	1.030	1.062
Scenario 2	0.956	0.980
Scenario 3	1.021	1.028

The table (7) populates the results of voltage deviation and overload for different scenarios, for before and after the placement of SVC. It is obvious from the results presented that the voltage profile has improved and is clearly visible in terms of the average value of load bus voltage as well. The effect of placement of SVC can be inferred on both the voltage deviation as well as the overload. In order to validate the proposed approach, the results are compared with those achieved by other optimization approaches namely BFOA and GA. The discussion is limited towards the optimal location and sizing for different scenarios. The influence of such placement on real power loss is also illustrated as an example to showcase the efficacy of the proposed method. The optimum location and sizing identified by different methods are listed in the table (8).

Table (7) Voltage deviation and overload before and after placement of SVC- Case 1

Operating Condition	VDBP of SVC (p.u.)	VDAP SVC (p.u.)	OVP of SVC	OAP of SVC
Scenario 1	0.029	0.021	10.56	9.07
Scenario 2	0.046	0.029	12.95	9.98
Scenario 3	0.049	0.301	10.88	9.26

VDBP=Voltage deviation Before Placement
VDAP= Voltage deviation After Placement
OVP= Overload Before Placement
OAP= Overload After Placement

Table (8) Comparison of optimal placement and sizing delivered by different approaches

Operating Condition	Proposed MBFOA		BFOA		GA	
	Location	Size	Location	Size	Location	Size
	SVC – Bus	SVC (MVAR)	SVC – Bus	SVC (VAR)	SVC Bus	SVC (MVAR)
Scenario 1	21	6.7325	20	6.2671	18	7.4520
Scenario 2	14	8.5468	17	9.6702	20	9.8213
Scenario 3	16	7.1002	8	7.5618	20	7.2451

The comparative analysis of real power losses for different optimization techniques is illustrated using the figure (4). It can be inferred from the figure the proposed approach delivers the best results in terms of reduction of real power losses.
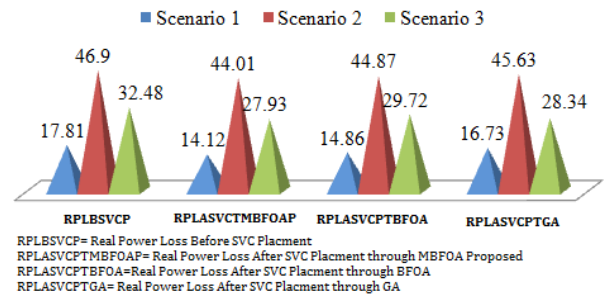

RPLBSVCP= Real Power Loss Before SVC Placment
RPLASVCPTMBFOAP= Real Power Loss After SVC Placment through MBFOA Proposed
RPLASVCPTBFOA=Real Power Loss After SVC Placment through BFOA
RPLASVCPTGA= Real Power Loss After SVC Placment through GA

Figure 4 Plot of real power losses for different scenarios optimized by different approaches

5.2. Case 2: Indian Utility Neyveli Thermal Power Station (IU-NTPS) 23 bus system
The second case is Indian Utility Neyveli Thermal Power Station (IU-NTPS). It is a 23 bus system. This system has 19 load buses and having 22 transmission lines. The salient feature of IU-NTPS is that it maintains the transmission lines with 4 generator buses. The bus 1 is the reference bus for determining the system data. The results are deduced for100 MVA. Outage of line 3 is considered the most critical line outages of the IU-NTPS - 23 bus system.

Table (9) optimal location and size of SVC optimized by the proposed approach-Case 2

Operating Condition	Location of SVC- Bus	Size of SVC (MVAR)
Scenario 1	13	6.13
Scenario 2	08	10.78
Scenario 3	20	9.04

The results of size and the optimal location of SVC for all the three scenarios are listed using the Table (9) and for this placement, the real power losses are calculated and tabulated using the Table (10).

Table (10) Comparison of real power loss before and after placement of SVC--Case 2

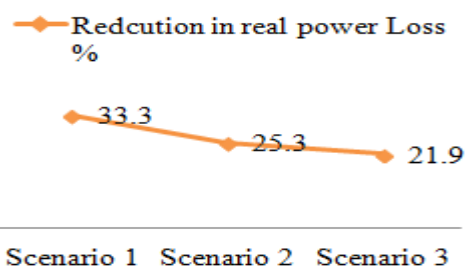| Operating Condition	Real Power loss before SVC placement (MW)	Real Power loss after placement of SVC (MW)
Scenario 1	13.5	9.0
Scenario 2	34.7	25.9
Scenario 3	27.4	21.4

Figure 5 Plot of percentage reduction in real power loss post SVC placement for different scenarios –case 2

The percentage reduction in real power loss after placement of optimized size of SVC in locations identified

by the algorithm is depicted using the figure (5).The percentage reduction in real power loss after placement of optimized size of SVC in locations identified by the algorithm is depicted using the figure (5). There is appreciable improvement in real power losses on account of placement of SVC. For scenario 1, which is the base case the algorithm identifies bus 13 as the optimum location and suggests a size of SVC to be 6.13 MVAR. This placement results in real power losses getting reduced by 4.5 MW, which translates to a reduction of 33.3 %. Similarly for scenario 2, the optimum size is identified to be 10.78 MVR placed at bus number 08. Such a placement results in reduction of real power losses from 34.70 MW to 25.90 MW.

Table (11) Minimum voltage profile for different scenarios--Case 2

Operating Condition	MVO at Bus number	VPBP of SVC (p.u.)	VPAP of SVC (p.u.)
Scenario 1	19	0.923	1.099
Scenario 2	19	0.913	0.989
Scenario 3	19	0.940	0.992
MVO=Minimum Voltage Occurring VPBP=Voltage Profile Before Placement VPAP=Voltage Profile After Placement			

This amounts to 25.3 % reduction in real power loss. Similarly when the critical line outage of line 3 is considered for location of SVC placement, the optimum bus is identified to be bus number 20 and the size is fixed at 9.04 MVAR. Similarly, the enhancement in voltage profile is tabulated through table (11) for different scenarios. It can be inferred from the table that for all the scenarios minimum voltage occurs at bus number 19. Through the location of SVC there is improvement in minimum voltage profile of these buses. Table (12) depicts the results of voltage deviation and overload for different scenarios, for before and after the placement of SVC. The positive effect of placement of SVC can be inferred on both the voltage deviation as the overload.

Table (12) Voltage deviation and overload before and after placement of SVC-Case 1

Operating Condition	VDBP of SVC (p.u.)	VDAP of SVC (p.u.)	OBP of SVC	OAP of SVC
Scenario 1	0.032	0.026	13.26	11.08
Scenario 2	0.049	0.032	15.23	13.32
Scenario 3	0.051	0.042	13.67	11.93
VDBP=Voltage Deviation Before Placement VDAP= Voltage Deviation After Placement OBP=Overload Before Placement OAP=Overload After Placement				

Like in case 1 the validation and efficacy of the proposed approach is illustrated by comparing the results of placements provided by original BFOA and GA. The results are compared with the help of Table 13. The comparative analysis of real power losses for different optimization techniques is illustrated using the figure (7). It can be inferred from the figure the proposed approach delivers the best results in terms of reduction of real power losses.

Table (13) Comparison of optimal placement and sizing delivered by different approaches- Case 2

Operating Condition	Proposed MBFOA		BFOA		GA	
	Location	Size	Location	Size	Location	Size
	SVC – Bus	SVC (VAR)	SVC-Bus	SVC (MVAR)	SVC-Bus	SVC (MVAR)
Scenario 1	13	6.13	16	6.73	16	7.54
Scenario 2	08	10.78	08	11.23	06	10.52
Scenario 3	20	9.04	13	10.01	13	12.13
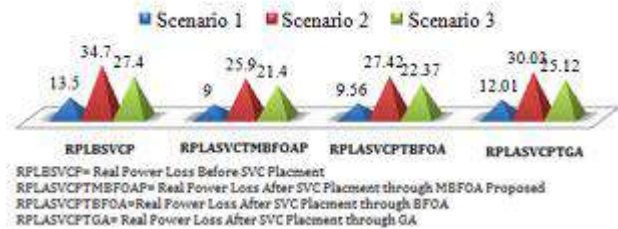
Figure 6 Plot of real power losses for different scenarios optimized by different approaches –Case 2

RPLBSVCP= Real Power Loss Before SVC Placment
RPLASVCPTMBFOAP= Real Power Loss After SVC Placment through MBFOA Proposed
RPLASVCPTBFOA=Real Power Loss After SVC Placment through BFOA
RPLASVCPTGA= Real Power Loss After SVC Placment through GA

In order to have an understanding of the cost of the FACTS devices the cost is computed using (13). The cost function is obtained from [32].The cost analysis is tabulated using table 14 case 1 and table 15 for case 2. It can be inferred from the tables that for both the cases, except for scenario 1 in case 1, the minimum cost of SVC is obtained for placement through the proposed approach.

$$CF\,(SVC\,) = 0.0003*(size\ of SVC\,)^2 - 0.3051(size of SVC\,) + 127.38\left(\frac{US\$}{KVAR}\right) \quad (13)$$

Table (14) Cost of placement of SVC as optimized by different approaches for different test scenarios in Case 1

Operating Condition	Proposed MBFOA		BFOA		GA	
	Size	Cost	Size	Cost	Size	Cost
	SVC (MVAR)	(K US$)	SVC (MVAR)	(K US$)	SVC (MVAR)	(K US$)
Scenario 1	6.732	855.242	6.267	796.121	7.452	946.643
Scenario 2	8.547	1085.721	9.670	1228.432	9.821	1247.627
Scenario 3	7.1002	901.952	7.5618	960.591	7.2451	920.360

Table (15): Cost of placement of SVC as optimized by different approaches for different test scenarios in Case 2

Operating Condition	Proposed MBFOA		BFOA		GA	
	Size	Cost	Size	Cost	Size	Cost
	SVC (MVAR)	(K US$)	SVC (MVAR)	(K US$)	SVC (MVAR)	(K US$)
Scenario 1	6.13	778.704	6.73	854.925	7.54	957.822
Scenario 2	10.78	1369.417	11.23	1426.583	10.52	1336.387
Scenario 3	9.04	1148.375	10.01	1271.599	12.13	1540.916

6. CONCLUSION

A modified BFOA approach for placement of SVC has been designed and presented. The multi-objective function comprising voltage deviation, system overload and real power losses was formulated and optimized using the modified BFOA. For all the cases, the proposed approach delivered the better results shown like the reduction in the real power loss, betterment in voltage profile, reducing the overload and limiting the voltage deviation. The results of comparison with other optimization approaches also testify the suitability of the present approach in identifying the location and size of SVC. The performance of the proposed approach

compared with BFOA and GA for cost and reduction in real power loss.

REFERENCE

[1]. N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission System", IEEE Press, 2000.

[2]. G W Stagg and A H El-Abid, 'Computer Methods in Power System Analysis', McGraw-Hill Book Co, 1968.

[3]. Camacho Yuryevich Janson, "Evolutionary programming based optimal power flow algorithm." IEEE Trans on Power Systems, 1999; 14(4):1245–50.

[4]. Canizares C A and Faur Z T (1999), "Analysis of SVC and TCSC Controllers in Voltage Collapse", IEEE Trans. on Power Systems, Vol. 14, No. 1, pp. 158-165.

[5]. A. H. Sekhar and A. L. Devi, "Voltage profile improvement and power system losses reduction with multi TCSC placement in transmission system by using firing angle control model with heuristic algorithms," 2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES), Paralakhemundi, 2016, pp. 295-301.

[6]. N. Archana and R. Vidhyapriya, "Location of multi-type facts devices under contingency: An intelligent approach using modified ABC," 2016 International Conference on Advances in Electrical, Electronic and Systems Engineering (ICAEES), Putrajaya, 2016, pp. 477-483.

[7]. I. G. Adebayo, M. A. Bhaskhar, A. A. Yusuff and A. A. Jimoh, "Optimal location identification of FACTS devices through genetic algorithm and the network structural characteristics techniques," 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA), Birmingham, 2016, pp. 778-782.

[8]. A. N. Zeinhom, "Optimal sizing and allocation of Unified Power Flow Controller (UPFC) for enhancement of Saudi Arabian interconnected grid using Genetic Algorithm (GA)," 2016 Saudi Arabia Smart Grid (SASG), Jeddah, 2016, pp. 1-6.

[9]. A. S. Telang and P. P. Bedekar, "Systematic approach for optimal placement and sizing of STATCOM to assess the voltage stability," 2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT), Nagercoil, 2016, pp. 1-6.

[10]. P. P. Kulkarni and N. D. Ghawghawe, "Optimal placement and parameter setting of TCSC in power transmission system to increase the power transfer capability," 2015 International Conference on Energy Systems and Applications, Pune, 2015, pp. 735-739.

[11]. A. Sheth, C. D. Kotwal and S. Pujara, "Optimal placement of TCSC for improvement of static voltage stability," 2015 5th Nirma University International Conference on Engineering (NUiCONE), Ahmedabad, 2015, pp. 1-6.

[12]. S. Dixit, G. Agnihotri, L. Srivastava and A. Singh, "An Overview of Placement of TCSC for Enhancement of Power System Stability," 2014 International Conference on Computational Intelligence and Communication Networks, Bhopal, 2014, pp. 1184-1187

[13]. D. Shchetinin and G. Hug, "Optimal TCSC allocation in a power system for risk minimization," 2014 North American Power Symposium (NAPS), Pullman, WA, 2014, pp. 1-6.

[14]. L. Srivastava, S. Dixit and G. Agnihotri, "Optimal location and size of TCSC for voltage stability enhancement using PSO-TVAC,"2014 Power & Energy Systems: Towards Sustainable Energy, Bangalore, 2014, pp. 1-6.

[15]. M. M. Eissa, T. S. Abdel-hameed and H. Gabbar, "A novel approach for optimum allocation of Flexible AC Transmission Systems using Harmony Search technique," 2013 IEEE International Conference on Smart Energy Grid Engineering (SEGE), Oshawa, ON, 2013, pp. 1-6.

[16]. Kennedy, J., Eberhart, and R.: "Particle swarm optimization". In: Proceedings of IEEE International Conference on Neural Networks, pp. 1942–1948 (1995).

[17]. Dorigo, M., Gambardella, L.M.: Ant Colony System: "A Cooperative Learning Approach to the Traveling Salesman Problem" IEEE Transactions on Evolutionary Computation 1(1), 53–66 (1999)

[18]. Holland, J.H.: "Adaptation in Natural and Artificial Systems" University of Michigan Press, Ann Harbor (1975)

[19]. Storm, R., Price, K.: "Differential evolution – A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces "Journal of Global Optimization 11(4), 341–359 (1997)

[20]. Passino, K.M. "Biomimicry of Bacterial Foraging for Distributed Optimization and Control". IEEE Control Systems Magazine, 52–67 (2002)

[21]. A. H. Sekhar and A. L. Devi, "Voltage profile improvement and power system losses reduction with multi TCSC placement in transmission system by using firing angle control model with heuristic algorithms," 2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES), Paralakhemundi, 2016, pp. 295-301.

[22]. N. Archana and R. Vidhyapriya, "Location of multi-type facts devices under contingency: An intelligent appproach using modified ABC," 2016 International Conference on Advances in Electrical, Electronic and Systems Engineering (ICAEES), Putrajaya, 2016, pp. 477-483.

[23]. I. G. Adebayo, M. A. Bhaskhar, A. A. Yusuff and A. A. Jimoh, "Optimal location identification of FACTS devices through genetic algorithm and the network structural characteristics techniques," 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA), Birmingham, 2016, pp. 778-782.

[24]. A. N. Zeinhom, "Optimal sizing and allocation of Unified Power Flow Controller (UPFC) for enhancement of Saudi Arabian interconnected grid using Genetic Algorithm (GA)," 2016 Saudi Arabia Smart Grid (SASG), Jeddah, 2016, pp. 1-6.

[25]. A. S. Telang and P. P. Bedekar, "Systematic approach for optimal placement and sizing of STATCOM to assess the voltage stability," 2016 International

Conference on Circuit, Power and Computing Technologies (ICCPCT), Nagercoil, 2016, pp. 1-6.

[26]. P. P. Kulkarni and N. D. Ghawghawe, "Optimal placement and parameter setting of TCSC in power transmission system to increase the power transfer capability," 2015 International Conference on Energy Systems and Applications, Pune, 2015, pp. 735-739.

[27]. A. Sheth, C. D. Kotwal and S. Pujara, "Optimal placement of TCSC for improvement of static voltage stability," 2015 5th Nirma University International Conference on Engineering (NUiCONE), Ahmedabad, 2015, pp. 1-6.

[28]. S. Dixit, G. Agnihotri, L. Srivastava and A. Singh, "An Overview of Placement of TCSC for Enhancement of Power System Stability," 2014 International Conference on Computational Intelligence and Communication Networks, Bhopal, 2014, pp. 1184-1187

[29]. Selvarasu, M. Surya kalavathi.C "SVC placement for voltage constrained loss minimization using self-adaptive firefly algorithm", Archives of electrical engineering, vol.62(4),pp. 649-661 (2013)

[30]. Matpower Version 5.1 user manual

[31]. https://www2.ee.washington.edu/research/pstca/

[32]. Biplab Bhattacharyya, Vikash Kumar Gupta, Sanjay Kumar, UPFC with series and shunt FACTS controllers for the economic operation of a power system, Ain Shams Engineering Journal, Volume 5, Issue 3, 2014, Pages 775-787

[33]. T. N. V. L. N. Kumar, Dr. R. V. S. Satyanarayana, "Optimal Location and Sizing of UPFC to Enhance Power System Security Using Modified BFOA", Current Trends in Technology and Science (CTTS), Volume: 6, Issue: 3, pp. 720-726.

[34]. T. N. V. L. N. Kumar, Dr. R. V. S. Satyanarayana, "Enhancing Power System Security through Optimal Location and sizing of TCSC through Modified BFOA", Journal of Advanced Research in Dynamical and Control Systems (JARDCS), Issue:17

[35]. T. N. V. L. N. Kumar, Dr. R. V. S. Satyanarayana, "A Modified BFOA Approach for Optimal location and Sizing of FACTS for Enhancing Power System Security", i-manager's Journal on Power Systems Engineering (JPS), Aug-Oct,2017.

[36]. T. N. V. L. N. Kumar, Dr. R. V. S. Satyanarayana, "Validation of Modified BFOA for Optimal Location and Sizing of SVC to improve Power System", Journal of Instrument Society of India (JISOI),September,2017.

[37]. T. N. V. L. N. Kumar, Dr. R. V. S. Satyanarayana," A Robust and Cost reduction Technique based on Multi-objective SVC for Enhancement of Power System Security", International Journal of Current Advanced Research (IJCAR), Accepted for November,2017.

[38]. T. N. V. L. N. Kumar, Dr. R. V. S. Satyanarayana, "Enhancing Power System Security – A Multi-objective Optimal Approach to Identify Location and Sizing of SVC", IUP-Journal of Electrical and Electronics Engineering (IUP-JEEE), Accepted for Jan, 2017.

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