Optimal placement of FACTS devices using optimization techniques: A review

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Abstract Modern power system is dealt with overloading problem especially transmission network which works on their maximum limit. Today’s power system network tends to become unstable and prone to collapse due to disturbances. Flexible AC Transmission system (FACTS) provides solution to problems like line overloading, voltage stability, losses, power flow etc. FACTS can play important role in improving static and dynamic performance of power system. FACTS devices need high initial investment. Therefore, FACTS location, type and their rating are vital and should be optimized to place in the network for maximum benefit. In this paper, different optimization methods like Particle Swarm Optimization (PSO), Genetic Algorithm (GA) etc. are discussed and compared for optimal location, type and rating of devices. FACTS devices such as Thyristor Controlled Series Compensator (TCSC), Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) are considered here. Mentioned FACTS controllers effects on different IEEE bus network parameters like generation cost, active power loss, voltage stability etc. have been analyzed and compared among the devices.

1. Introduction
Today’s power system becomes more complex interconnected system due to alarming increase in load demand and dynamic load pattern which affect severely on transmission lines. They are operating either overloaded or under loaded. The uneven load distribution affects voltage profile and makes system voltage security vulnerable to the fault. It becomes difficult to maintain power system security and reliability. Conventional approach of add new transmission lines in the system and build new power generation facilities is bound with certain factors such as technical and economical bounds. So the best and necessary solution left is to make optimal use of existing generation and transmission network. FACTS controllers are the best and effective alternative for power system performance improvement like voltage security, transfer capability and reduction in losses etc. instead of making complex new transmission corridor. These devices can be connected in series, shunt, series-series and series-shunt. It is important to decide FACTS devices type according to the purpose of need. For voltage control at the point, shunt controllers are desirable and power flow in the line can be controlled through series controllers [1].

In 1999, Hingorani and Gyugyi introduced the concept of FACTS. Modulation and alteration of line power flow becomes accurate, fast and precise manner is attainable with FACTS concept [2]. The core of FACTS controllers is basic power electronics devices. FACTS devices applications include enhancement of transmission lines power transfer capacity and regulate different parameters in transmission network.
such as current, impedance, phase angle and voltage. Power flow can be made flexible or controllable using these devices. FACTS devices helps to increase loadability of the network through reduction of power flow in overloaded lines and line losses also reduced [3].FACTS devices effectively tackle the problem of voltage collapse and system security. These devices help in the problem of Congestion management. System accommodated the changes easily with FACTS devices [4].

Optimal location and settings of FACTS controllers play an important role for enhancement of system performance and economic benefits. In the past, several approaches are proposed by researchers to work out the problem of optimal location of FACTS devices. Common techniques of placement of devices are categorized into analytical, linear programming and heuristic search methods. The problem of optimal location is considered as combinatorial analysis and heuristic search methods are best tools for such problems as they are robust, fast and best suited for real problems of the power system. Common heuristic search methods proposed for optimal placement in research are Genetic Algorithm (GA), Differential Evolution (DE), Particle Swarm Optimization (PSO), Harmony Search Algorithm (HSA), and Ant Colony Optimization (ACO) [5].

In this paper, different optimization approaches especially heuristic approach for different parameters and their results are reviewed and compared. Literature regarding optimal location and ratings of SVC, TCSC and STATCOM using optimization technique especially GA are reviewed. Different objective functions and bus networks are considered and separately each FACTS devices effects on certain parameters of bus network such as generation cost, losses, voltage profile etc. are represented in tabular form. Comparison of different FACTS devices on the ground of parameters affected like reduction in active losses, improvement in voltage profile, minimization of cost etc. This paper compares different search techniques and review of recent techniques in literature and show effectiveness of individual FACTS devices for various parameters for a given bus network. This paper has following sections: II. FACTS devices and their mathematical models, III. Recent optimization techniques, IV. FACTS Applications using GA, V. Conclusion, VI. Research Scope.

2. Recent Optimization Techniques

2.1 Particle Swarm Optimization (PSO)

PSO method was introduced in 1995 by Dr. Kennedy and Eberhart. PSO is motivated by swarm intelligence like fish school and bird flocks etc. In birds, social interaction with each other and with environment to search the food is the basis of PSO. In PSO, compared to GA few parameters need to be changed and it is easy to implement. PSO has been used to loading of branch and voltage stability maximization and minimization of losses on IEEE 30 bus network using TCSC and SVC together at optimal location. In [6], Result of PSO method has been compared with Evolutionary Programming (EP) and it was concluded that loading factor (182%) increased more with minimum number of FACTS devices in PSO as compared to EP. PSO is faster than EP.

Kavitha et al. in [7] presented the comparison of WIPSO (improved weight PSO), BBO (Biogeography optimization) and PSO methods for number of FACTS devices, optimal location, type, rating of SVC and TCSC. Objective functions which consist of load voltage deviation, cost and line loadings are considered. Implementation has been done on IEEE 30, 57 and 14 bus systems. Analysis of result shows that WIPSO performs better than PSO and BBO perform best compared to WIPSO and PSO. SVC and TCSC optimally placed together gives better voltage profile security compared to when placed individually.

PSO is more popular compared to other due to its advantages such as easy implementation, low computational time, robustness and rapid convergence. Comparison of PSO with different methods through pie chart shown in Figure 1 [8].
Inkollu et al. in [9], proposed new technique which is a hybrid of PSO and Gravitational Search Algorithm (GSA). PSO has been used for optimizing the gravitational constant of GSA to improve its search performance and it has been used to find the optimal location and rating of FACTS devices. Interline Power Flow Controller (IPFC) and Unified Power Flow Controller (UPFC) is considered. The objective function has been made on the basis of voltage collapse and power loss. Technique has been implemented on IEEE 30 bus network. Comparison made between PSO-GSA and GA-GSA technique and it has been observed that computation time is less in former technique. Venkatesh et al. in [10], presented PSO method used for optimal location of FACTS controller for enhancing the Available Transfer Capability (ATC) of the system. FACTS devices considered are SSSC, STATCOM, UPFC on six bus network.

2.2 Genetic Algorithm
It is a natural genetic based evolutionary technique inspired by Darwin theory of survival of fittest. It comprises three operators: selection, crossover and mutation applied at each iteration. Adebayo et al. presented new method called Network Structural Characteristics Techniques (NSCT) to search optimal location of FACTS controllers such as TCSC and UPFC and compared it with GA. Both methods are implemented on IEEE 14 bus network. Generation and devices cost function minimization has been taken as the objective. It has been observed from simulation that NSCT is more superior than GA due to less time consumption and no iteration for searching optimal location of FACTS controllers. Total computational time for GA is 6.73 sec and for NSCT is 1.23 sec [11].

Khandani et al. proposed hybrid of GA and Sequential Quadratic Programming (SQP) to find optimal location of SVC and solution of Optimal Power Flow problem for enhancement of TTC. GA method is relatively slow but does not depend on initial point while SQP depends on initial point and cannot handle discrete variables, hybrid model takes advantage of both. This hybrid method has been implemented on IEEE 5 bus system. It has been shown that SVC at position 2 is the optimal place for enhancement of TTC [12].

Rashed et al. discussed the enhancement of loadability of the system by optimally placed multiple TCSC in the system with the help of PSO and GA. Minimizing investment cost of devices taken as objective function with voltage limits and thermal limits of lines as constraint. IEEE 6 and 14 bus networks are used for simulation results. In 6 bus network, active power flow in line by installing 3 TCSC’s optimally improves 39% with GA and 43% with PSO. Similarly, in 14 bus network, with 5 TCSC, 20% improvement with GA and 29% with PSO. Maximum loadability increase in 6 and 14 bus system are 15% and 22% respectively. By the comparison of two methods, it has been shown that PSO is faster than GA. It is found that TCSC is the one of most effective device to increase the system loadability [13].

2.3 Brainstorm Optimization Algorithm (BSOA)
BSOA technique was proposed by Shi in 2011 and its idea comes from brainstorming procedure in human species. BSOA development based on the notion that human beings are considered most intellect creatures
so algorithm motivated by their approach of problem solving is considered best over algorithms inspired by ants, birds, bees etc. It contains four operations: initialization, clustering, cluster center perturbation, individual perturbation.

A. R. Jordehi in [14] presented BSOA approach with eight other approaches i.e. PSO, GA, Simulated Annealing (SA), Backtracking Search Algorithm (BSA), DE, hybrid of Genetic Algorithm and Pattern Search (GA–PS), Asexual Reproduction Optimization (ARO) and GSA are used for optimal allocation of FACTS controllers such as SVC and TCSC on IEEE 57 bus network and comparisons are made. BSOA emerged best among other techniques to minimize power loss and voltage deviation of the system. In context of TCSC, it has been observed that the main work of TCSC helps to control power flow but also shows the effectiveness to enhance voltage security of the network.

2.4 Gravitational Search Algorithm (GSA)

GSA is a meta-heuristic technique developed in 2011 based upon Newton’s law of gravity and motion. In this technique, each agent is associated with mass. Agent with heaviest mass among other attract low mass agents according to the Newton law of gravitation and the position of heaviest mass agent considered as optimal solution in the search area.

Bhattacharyya et al. in [15] applied GSA method for optimal placement of SVC and TCSC to increase the system loadability and power transfer capability of generators. The proposed approach is compared with DE, PSO and GA. The techniques are applied on IEEE 57 and 30 bus network. It has been shown that GSA is most effective in minimizing operating cost and active power loss compared to others.

2.5 Adaptive Evolutionary Algorithm (AEA)

Evolutionary methods are potent algorithms for multi-objective optimization problem where optimal solutions can be found in one simulation run. EA’s does not required problem information that is being solved unlike classical methods [16].

The main challenge evolutionary method is dealt with maintaining its population diversity to avoid premature convergence. The proposed AEA method in [17] provides control of population diversity to prevent premature convergence and maintain the global search. In the paper, AEA method performance compared with PSO, SA and EA on the basis of L-index, voltage deviation, and reactive power loss. AEA emerged superior compared to other methods on IEEE 57 bus network and it outperforms for voltage deviation minimization in IEEE 14 bus system. It was shown that AEA is better than standard EA.

2.6 Moth Flame Algorithm (MFA)

MFA technique is proposed by Seyedali Mirjalili, inspired by moth navigation in environment called transverse orientation. In night, moth travel in straight direction by maintaining specific angle with moon for long distances but these insects trapped in circular or spiral paths around artificial lights. Mathematical modeling of this travelling behavior is done for optimization.

M. Ebeed et al. in [18] presented MFA method for optimal setting of STATCOM for voltage profile and stability improvement and loss minimization. Comparison of MFO with PSO has been done and validated on IEEE 30 bus network. MFA emerged more superior than PSO in stabilizing voltage deviation and minimize power losses with STATCOM like power loss minimized by 6 and 4 percent respectively by MFO and PSO respectively. It has been shown that STATCOM is effective for voltage profile improvement and loss minimization.

2.7 Imperialistic Competitive Algorithm (ICA)

Atashpaz-Gargari and C. Lucas developed novel meta-heuristic technique ICA which is motivated by the imperialism and socio-political development of human beings. Each candidate is treated as country and become either a colony or an imperialist.
A. R. Jordehi in [19] discussed TCSC and Thyristor Control Phase Shifting Transformer (TCPST) optimal placement by ICA on IEEE 14 bus system.

ICA outperforms some state of art methods like Evolutionary Programming (EP), Artificial Bee Colony (ABC), Bat Swarm Optimization (BSO), GSA. It has been shown that FACTS devices installation made the system secure at the time of contingencies and load growth with ICA.

2.8 Adaptive Cuckoo Search Algorithm (ACSA)
Suash Deb and Xin-She Yang introduced meta-heuristic CSA technique in 2009 inspired from search method of cuckoo bird species for laying eggs. Cuckoo bird lays eggs on other birds nest and they search the nest through levy flights or random walks. Mathematical modeling including step size parameter and probability inspired from above behavior leads to CSA. In ACSA, only step size parameter is removed for search of next nest instead value of best best nest updated based on current best nest.

Taleb et al. proposed ACSA for the optimal location of TCSC in IEEE 9 bus network for minimum bus bar voltage and minimizing active and reactive power loss. Evaluation of result of ACSA with PSO and GA has been done. It has been found out that minimum bus voltage reduced by 0.62% in comparison of PSO and GA. Overall active and reactive power loss is more reduced than PSO and GA [20].

3. FACTS applications using GA
In this section, overview of FACTS devices optimal placement, type and size using Genetic Algorithm with consideration of various objective functions (single and multi-objective) with different equality/inequality constraints are analyzed and study the effect of FACTS on different parameters of power system. The device considered mainly is SVC and TCSC. Table.1 and Table.2 shows Multi and single objective function optimization using GA with different bus system.

In [21], [23, [26], [30], [35] from table.1 and [38], [43], [46], [49] from table.2, it is inferred that TCSC has been used to enhance the performance of system by affecting various parameters like reducing generation cost, reducing active and reactive power loss, improving voltage stability by decreasing L-index, improving total transfer Capability (TTC), controlling the active power flow, enhancement of stability margin (SM) etc. It is found in [26], that cost of 10 MVAR TCSC installed in IEEE 30 bus network for voltage stability and reduction in losses is 1,53,000 US$. Similarly for 13 MVAR, cost of TCSC is 1,881,500 US$.

In [22], [24], [32], [36], [39], it is observed that SVC has been used to reduce generation cost reduction, active and reactive power loss reduction. STATCOM has been used in [40], [48], [50] for improvement in voltage stability, loadability and in loss reduction. It is seen in [48] that 60 MVAR STATCOM cost 10.8 million US$ in IEEE 14 bus network for improving voltage security.

It is observed from [44], that active power loss increases when SVC and TCSC are used together in IEEE 30 bus network but reactive power loss decreases significantly. In [37], it has been concluded that TCSC is more effective than SVC for enhancing the voltage stability of the 14 bus power system and generation cost reduction is nearly same in both the cases. It is inferred from [29] and [31] that active power loss reduces more in case of SVC than TCSC for IEEE 5 bus system and TCSC is more effective to reduce reactive power loss in IEEE 30 bus system. TCSC is best suited FACTS device among other for loadability enhancement.

In single type optimization, it has been shown that TCSC is the most effective device over Thyristor Controlled Phase Shifting Transformer (TCPST) and Thyristor Controlled Variable Reactor (TCVR) for enhancement of system loadability. TCSC drives the power in other direction to reduce loading on the line. [25].Nireekshana et al. shown that TCSC is better than SVC for ATC enhancement when the same bus–to–bus transactions are chosen [47].Karami et al shown the cost benefit analysis of STATCOM in which
active power losses reduction saves 80 million$ and this study shows that tradeoff between STATCOM initial cost and saving from losses gives benefit of 69.3 million $. [50]. Rashed et al presented Differential Evolution (DE) technique and compared it with GA. DE technique has superiority over GA in some features like high quality solution, stable convergence etc. [46].

### Table 1. Multi-objective optimization

| Objective functions | Multi-objective function | Equality/Inequality Constraints | Test Bus and Optimal location | Rating of device | Parameters affected |
|---------------------|--------------------------|---------------------------------|-----------------------------|-----------------|-------------------|
| **Investment cost function** | $C_{i}(f)= \text{depends on type of FACTS device}$ | $\text{Equality const.}$ $E(f,g)=0$ | $10$ bus system | capacitive | Generation cost reduced from $1117.75$ to $915.90$ US$/hour$ |
| **Bid function** | $C_{b}(P_{d}) = P_{min}P_{d}$ | $\text{Inequality const.}$ $B_1(f) < b_1, B_2(g) < b_2$ | $\text{TCSC between bus 4-5}$ | $70\%$ of $X_{max}$ | $0.98$ $\text{MVAr}$ |
| **For real power loss** | $F_{l}(u,v) = \sum_{i=1}^{m} \left[ u_i^2 + v_i^2 - 2u_i\text{cos}(\delta_i - \delta_j) \right]$ | $\text{Equality Const.}$ $P_{ai} - P_{bi} - P(V,\delta) = 0$ $Q_{ai} - Q_{bi} - Q(V,\delta) = 0$ | $30$ bus system | capacitive | $11.04$ $\text{MVAr}$ |
| **For voltage deviation** | $F_{v}(u,v) = \sum_{i}^{m} \delta_i$ | $\text{Inequality Const.}$ $Q_{min} \leq Q_{ai} \leq Q_{max}$ | $30$ (for LO 36) | $70\%$ of $X_{max}$ | $15.42$ $\text{MVAr}$ |
| **For SVC size** | $F_{s}(\text{SVC size}) = \text{Rating of SVC in p.u.}$ | $\text{Fitness} = \frac{1}{C_{T}+W(Q_{max} - P_{max} - P_{min})}$ | $28$ (for LO 5) | Inductive | $1.55$ $\text{MVAR}$ |
| **Total cost function** | $C_{T}=C_{i}(f)+C_{b}(P_{d})$ | $\text{Equality const.}$ $E(f,g)=0$ | $9$ bus system | capacitive | $15.42$ $\text{MVAr}$ |
| **For real power losses** | $Q_{ai} = \sum_{i=1}^{m} \left[ (u_i^2 + v_i^2) - 2u_i\text{cos}(\delta_i - \delta_j) \right]$ | $\text{Inequality const.}$ $B_1(f) < b_1, B_2(g) < b_2$ | $13$ bus system | capacitive | $62.989$ $\text{MVAR}$ |
| **For voltage deviation** | $Q_{ai} = \sum_{i=1}^{m} \left[ (u_i^2 + v_i^2) - 2u_i\text{cos}(\delta_i - \delta_j) \right]$ | $\text{Equality Const.}$ $P_{ai} - P_{bi} - P(V,\delta) = 0$ $Q_{ai} - Q_{bi} - Q(V,\delta) = 0$ | $9$ bus system | capacitive | $14.3$ $\text{MVAr}$ |
| **For installation cost** | $Q_{ai} = \sum_{i=1}^{m} \left[ (u_i^2 + v_i^2) - 2u_i\text{cos}(\delta_i - \delta_j) \right]$ | $\text{Inequality Const.}$ $S_i \leq S_{max}$ $U_{min} \leq U_{nom} \leq U_{max}$ | $13$ bus system | capacitive | $25.886$ to $22.432$ |

Table 1. Multi-objective optimization
For BL
$\Omega_{line} = e^{\lambda_{\text{line}}(100-\text{BL})}$,
>100% loading
1, <100% loading

For BVL
$V_{t\text{g}bus} = 1, 0.95 < V_t < 1$
$e^{\lambda_{\text{bus}}(V_t-1)}$, otherwise
BL= branch loading
BVL= bus voltage loading

Reactive power loss
$\text{Reactive power loss} = \sum_{i=1}^{n} Q_{\text{loss}}$

Voltage stability margin
Equality const.
$P_{cl} - P_{dl} - P(V, \delta) = 0$
$Q_{cl} - Q_{dl} - Q(V, \delta) = 0$

For SVC
$\text{30 bus system}$
30 bus system
For TCSC
line 10-22
line 10-20

Cost of FACTS controllers
Equality const.
$\sum_{i=1}^{n} P_{cl} - P_{dl} = 0$
$\sum_{i=1}^{n} Q_{cl} - Q_{dl} = 0$

Objective function
$\text{Min } f(x) = [f_1(x), f_2(x), f_3(x)]$

Cost of FACTS controllers
Equality const.
$\text{Cost of FACTS controllers} = \text{Cost of SVC} + \text{Cost of TCSC}$

Generation cost function
Equality const.
$\text{Objective function} = \min \{C_{\text{SVC}}(P_G) + C_{\text{TCSC}}(P_G)\}$

Power loss
Objective function
$P_{\text{loss}} = \sum_{j=1}^{m} \text{loss}_j$

For SVC
$\text{Bus 24 for min. cost}$
4.2 MVAR
Bus for min. cost
50 MVAR

Fuel cost
$\text{Fuel cost} = \min \{C_{\text{SVC}}(P_G) + C_{\text{TCSC}}(P_G)\}$

For TCSC
$\text{Line 27 for minimum cost}$
30.6% Xline
For SVC
$\text{Bus 24 for min. cost}$
29% Xline

Fuel cost
$\text{Fuel cost} = \min \{C_{\text{SVC}}(P_G) + C_{\text{TCSC}}(P_G)\}$

For SVC
$\text{Bus 8 for min. cost}$
50 MVAR
### VSI (L index)

\[
L_j = 1 - \sum_{i=1}^{g} F_j P_i^U_i P_i^L_i
\]

Fitness fn

\[
e_{3}^{j} = \alpha_{3}^{j}(\text{max } L_j) + \alpha_{3}^{j} (\text{cost fn}) + \alpha_{3}^{j} (\text{lo}sse)s
\]

Equality const.

\[
S^{h}(V^{F}, \theta, u^{h}) = 0
\]

30 bus system

TCSC

13 MVA

Bus 2-4

SVC

97.18 MVA

Bus 18

VSI = voltage stability index

\[
\text{FACTS cost fn.}
\]

| Ctcsc | 0.015$s^2 - 0.7130s + 153.75 (US$/kvar) |
|-------|-----------------------------------------|

\[
C_{svc} = 0.0003s^2 - 0.3051s + 127.38 (US$/kvar)
\]

Cost function

\[
g = \sum_{i=1}^{f} f_i(S_i)
\]

Line flow limits

\[
g = \prod_{i=1}^{f} f_i(p_i)
\]

Active power losses

\[
g = p_n = \text{Re} (\sum_{i} Y_{ij} V_i')
\]

\[
g = \text{ATC} = \text{TTC-ETC}
\]

Cost function

\[
C_G(p_G) = a_{Gi} + b_{Gi}p_G + c_{Gi}
\]

Benefit function

\[
B_{Dj}(p_D) = d_{Dj} p_D - e_{Dj}
\]

### Objective Function

\[
\text{Fitness function} = a_1*(\text{max } L_j) + a_2 (\text{cost fn}) + a_3 (\text{losses})
\]

\[
a_1 = 2.78
\]

\[
a_2 = 0.1
\]

\[
a_3 = 2.05
\]

\[
\text{FACTS devices cost fn.}
\]

\[
\text{VSI} = \text{voltage stability index}
\]

\[
\text{Cost function}
\]

\[
C_f(p_G) = a_{cG} + b_{cG}p_G + c_{cG}p_G^2
\]

### Equality const.

\[
E(f,g) = 0
\]

### Inequality const.

\[
B_1(f) < b_1, B_2(g) < b_2
\]

### Power flow equations

\[
E(f,g) = 0
\]

### Overall obj. function

\[
m = \text{cost (FACTS)}
\]

\[
\text{Total cost function}
\]

\[
C_f = C_f (f) + C_G (p_G)
\]

\[
\text{Overall obj. function}
\]

\[
m - C_{total}
\]

\[
\text{Total cost function}
\]

\[
C_f(p_G) = a_{cG} + b_{cG}p_G + c_{cG}p_G^2
\]

### Equality const.

\[
F(g) = 0
\]

### Inequality const.

\[
B_1(f) < b_1, B_2(g) < b_2
\]

### Capacitive

\[
\text{Loss reduced from 3.006 to 2.321 MW}
\]

\[
\text{TTC increase from 70.25 to 86.85 MW}
\]
### Voltage Stability Index (VSI)

\[ F_1 = \frac{L_{\text{max}}}{g_{3627} / g_{1838} / g_{3037} / g_{3627}} = \frac{1}{g_{3628}} - \sum g_{3036} / g_{3106} / g_{3080} / g_{3256} / g_{3004} / g_{3284} / g_{3285} / g_{3023} / g_{3284} / g_{3023} / g_{3285} \]

### Generation Cost Function

\[ F_2 = C_{CGi}(P_G) = a_{Gi} + b_{Gi} P_G + c_{Gi} \]

### For Real Power Loss

\[ F_3 = \sum_{i=1}^{n} \left[ \left| q_i v_i^2 + v_i^2 - 2v_i v_j \cos(\delta_i - \delta_j) \right| \right] \]

### Objective Function

\[ F = h_1 F_1 + h_2 F_2 + h_3 F_3 \]

### Equality Constraint

\[ \sum_{i=1}^{n} P_G = P_D - P_L = 0 \]

### Inequality Constraint

\[ P_{\text{loss}} < P_{\text{loss max}} \]

\[ Q_{G} < Q_{G \text{max}} \]

\[ S_{ij} < S_{ij \text{max}} \]

\[ V_{i} < V_{i \text{max}} \]

\[ X_{\text{tcsc min}} < X < X_{\text{tcsc max}} \]

### Generation Cost Reduced

- SVC at 5th bus: 51.66 MVAR
- TCSC at 9-14 bus: 22.91 MVAR
- Overall Objective Function: 51.66 MVAR

### Fitness Function

\[ F_i = C_{CGi} + C_{CGi} \]

### System Security

\[ F_i = \frac{\sum_{j=1}^{n} W_i \left( \frac{s_{\text{max}}}{s_{\text{max}} - s_{\text{max}}^*} \right)^2}{\sum_{j=1}^{n} W_i \left( \frac{v_{\text{max}} - v_{\text{max}}^*}{v_{\text{max}} - v_{\text{max}}^*} \right)^2} \]

\[ F_i = C_{CGi} + C_{CGi} \]

### Overall Objective Function

\[ FC = C_{CGi} + C_{CGi} \]

### Equality Constraint

\[ E(f, g) = 0 \]

### Inequality Constraint

\[ B(f) < b_1 \quad B(g) < b_2 \]

### Fitness Function

\[ F_i = \min C_i = [ F_i(x), F_j(x) ] \]

### System Security

\[ F_i = \frac{\sum_{j=1}^{n} W_i \left( \frac{s_{\text{max}}}{s_{\text{max}} - s_{\text{max}}^*} \right)^2}{\sum_{j=1}^{n} W_i \left( \frac{v_{\text{max}} - v_{\text{max}}^*}{v_{\text{max}} - v_{\text{max}}^*} \right)^2} \]

\[ F_i = C_{CGi} + C_{CGi} \]

### Equality Constraint

\[ E(f, g) = 0 \]

### Inequality Constraint

\[ B(f) > b_1 \quad B(g) < b_2 \]
Table 2. Single objective optimization

| Objective functions | Equality/Inequality Constraint | Test bus and Optimal location | Rating | Parameters affected |
|---------------------|--------------------------------|-------------------------------|--------|--------------------|
| Obj. fcn = max $\lambda$ | $\lambda$ is system loading factor | 4 bus system | TCSC at line 3 | Capacitive $23\% X_{bus}$ |
|                     | [38]                           |                               |        |                    |
|                     | Equality const.                |                               |        |                    |
|                     | $P_{gi} - P_{di} - \sum |V_i| |V_j| | (G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij}) = 0$ |                     |        |                    |
|                     | $Q_{gi} - Q_{di} - \sum |V_i| |V_j| | (G_{ij} \sin\delta_{ij} - B_{ij} \cos\delta_{ij}) = 0$ |                     |        |                    |
|                     | Inequality const.              |                               |        |                    |
|                     | $V_{vmin} < V_i < V_{imax}$ |                               |        |                    |
|                     | $0.5 \times X_{bus} < X_{TCSC} < 0.5 \times X_{bus}$ |                     |        |                    |
|                     | Susceptance equation           |                               |        |                    |
|                     | $B_{VASC} = B_{VASC} + \Delta B_{VASC} / B_{VASC}$ | 9 bus system | SVC at 9th bus(NL) | B = 46.77 siemens |
|                     | [39]                           |                               |        | Q loss reduced from 79.55 to 4.73 |
|                     | Equality const.                |                               |        |                    |
|                     | $\sum^{N_{bus}}_{i=1} P_i - P_0 - P_2 = 0$ |                     |        |                    |
|                     | Inequality const.              |                               |        |                    |
|                     | $P_{g_{min}} < P_i < P_{g_{max}}$ |                               |        |                    |
|                     | $Q_{g_{min}} < Q_i < Q_{g_{max}}$ |                               |        |                    |
|                     | $S_i < S_{\max}$              |                               |        |                    |
|                     | $|V_i| \leq 0.05$               |                               |        |                    |
|                     | For voltage stability          |                               |        |                    |
|                     | $\sum_{i} \text{abs} \left| v_i - v_{ref} \right|^5$ | 68 bus system | (in MVAR) |                    |
|                     | [41]                           |                               |        |                    |
|                     | Equality const.                |                               |        |                    |
|                     | $\sum^{N_{bus}}_{i=1} P_i - P_0 - P_2 = 0$ |                     |        |                    |
|                     | Inequality const.              |                               |        |                    |
|                     | $P_{g_{min}} < P_i < P_{g_{max}}$ |                               |        |                    |
|                     | $Q_{g_{min}} < Q_i < Q_{g_{max}}$ |                               |        |                    |
|                     | $S_i < S_{\max}$              |                               |        |                    |
|                     | $|V_i| \leq 0.05$               |                               |        |                    |
|                     | Obj. fcn = Maximize $\lambda$  |                               |        |                    |
|                     | $\lambda$ is system loading factor | 14 bus system | For SVC at bus 9 | $\lambda$ improved from 3.9752 to 4.11 |
|                     | [42]                           |                               |        |                    |
|                     | Equality const.                |                               |        |                    |
|                     | $\sum^{N_{bus}}_{i=1} P_i - P_0 - P_2 = 0$ |                     |        |                    |
|                     | Inequality const.              |                               |        |                    |
|                     | $P_{g_{min}} < P_i < P_{g_{max}}$ |                               |        |                    |
|                     | $Q_{g_{min}} < Q_i < Q_{g_{max}}$ |                               |        |                    |
|                     | $S_i < S_{\max}$              |                               |        |                    |
|                     | $|V_i| \leq 0.05$               |                               |        |                    |
|                     | min F =                        |                               |        |                    |
|                     | $\sum_{i=1}^{N_{bus}} Q_{gi} + \sum_{i=1}^{N_{bus}} P_{gi} +$ | 30 bus system | TCSC at Line 2 | Capacitive $40\% X_{bus}$ |
|                     | $\sum_{i=3}^{N_{bus}} Q_{gi}$ |                               |        | Increase by 10 MW |
|                     | [43]                           |                               |        |                    |
|                     | Equality const.                |                               |        |                    |
|                     | $P_{g_{min}} < P_i < P_{g_{max}}$ |                               |        |                    |
|                     | $Q_{g_{min}} < Q_i < Q_{g_{max}}$ |                               |        |                    |
|                     | $\sum_{i=1}^{N_{bus}} P_i - P_0 - P_2 = 0$ |                     |        |                    |
|                     | Inequality const.              |                               |        |                    |
|                     | $P_{g_{min}} < P_i < P_{g_{max}}$ |                               |        |                    |
|                     | $Q_{g_{min}} < Q_i < Q_{g_{max}}$ |                               |        |                    |
|                     | $S_i < S_{\max}$              |                               |        |                    |
|                     | $|V_i| \leq 0.05$               |                               |        |                    |
|                     | Active flow                    |                               |        |                    |
|                     | TCSC at Line 2                 |                               |        |                    |
|                     | Line 3                         |                               |        |                    |
|                     | Capslative $2.8\% X_{bus}$    |                               |        | Increase by 0.64 MW |
|                     | Increase by 10 MW              |                               |        |                    |
|                     | 30 bus system                  |                               |        |                    |
|                     | 14 bus system                  |                               |        |                    |
|                     | 68 bus system                  |                               |        |                    |
|                     | 9 bus system                   |                               |        |                    |
MinF = ∑_{i=1}^{n} P_{i} \leq P_{i}^{max} (46)
\[ Z = \text{MANP} \times \text{VANP} \]

Equality const.
\[ G(X,P,Q) = 0 \]

Inequality const.
\[ H(X,P,Q) < 0 \]

\[ \frac{1}{n} \sum_{i=1}^{n} (P_i - \text{MANP})^2 \]

\[ Z \text{= objective function} \]
\[ \text{VANP} \text{= variance of nodal price} \]

[48]

\[ J = \left( |V_p| - V_{ref} \right)^2 + (1-SM)^n_r \]

Equality const.
\[ \sum_{i=1}^{N} P_{ci} - P_{ave} = 0 \]

Inequality const.
\[ X_{min} < X < X_{max} \]
\[ 0.95 < V_{bus} < 1.05 \]

[49]

\[ \text{Max } F(u) = (\lambda - \lambda_0) \]
\[ \lambda = \text{distance between operating and collapse point} \]

Equality const.
\[ f(\lambda, \lambda_0, p) = 0 \]

\[ D^2 F (x, \lambda, p, w) = 0 \]

\[ D^2 _p = \text{jacobian matrix} \]

4. Conclusion

In this paper, recent optimization techniques are discussed such as Particle Swarm Optimization (PSO), Genetic Algorithm, Brainstorm Optimization Algorithm (BSOA), Gravitational Search Algorithm (GSA), Adaptive Evolutionary Algorithm (AEA), Moth Flame Algorithm (MFA), Imperialistic Competitive Algorithm (ICA), Adaptive Cuckoo Search Algorithm (ACSA) and compared among each other. It has been observed that recent methods are generally inspired by human behavior like BSOA, ICA etc and show good performance to solve practical problems. They outperformed conventional heuristic methods like GA and PSO in speed.

The other part of the paper presents analytical review on optimal location of FACTS devices mainly SVC, TCSC and STATCOM. Different bus system and objective function for various parameters optimization has been studied e.g. for minimization of generation cost, active power losses and investment cost of FACTS and regarding voltage stability.

Power system parameters changes with and without FACTS devices has also been considered. It can be concluded that FACTS devices enhance system performance and maintain system security at the time of contingencies. This paper will be helpful for choosing specific type of FACTS devices on the basis of different objective.

5. Future Scope

It has been observed that hybrid optimization techniques are more effective, robust and fast to search the particular solution. More work can be done to develop the hybrid optimization technique from recent methods.
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