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Optimal Location of TCSC and SVC using Hybrid Fruit Fly Firefly Optimization Algorithm in Transmission System

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Abstract: In the modern market of power system, obtaining an optimal placement and setting up the FACTS devices epitomizes an onerous optimization problem. This is due to its cogent objective function along with multimodal nature. This study presents a solution methodology for optimal placement of Thyristor Controlled Series Capacitor (TCSC) and Static VAR Compensator (SVC) as FACTS devices in transmission system. This multi objective function is solved by employing a hybrid Fruit Fly Firefly Algorithm (FFFA) based optimization technique. The proposed model is demonstrated using IEEE30 bus system and the results obtained are validated by comparing the obtained result with existing optimization approaches. The results indicate that the proposed algorithm is capable of finding best location for placing TCSC and SVC.

Key words: Thyristor controlled series capacitor, static VAR compensator, fruit fly algorithm, fire fly algorithm, IEEE 30 bus system

INTRODUCTION

With the continuous expansion of power networks in congruence to the load demands, power transfer capability and power system stability has raised a complex problem to resolve the network system. When the power system network is been operated close to its voltage stability limits, it results an unfavorable dynamic performance with reduced controllability to reactive power demand in the network. Also, the voltage instability is hampered due to the sag in reactive power at different locations in interconnected networks. This affects certainly the revenue of power generating companies, thereby back lashing the efficiency of the entire system. Utilization of FACTS devices in power system has authenticated to be a favorable solution for the above problems in the power system. These devices helps to control the power flow in the power system network eventual zing low system losses, improve stability and load ability of the networks. Hence, this also makes a critical choice to ascertain the location for placement of FACTS devices in the immense power system network.

Locations of FACTS devices in power system are mainly obtained on the basis of static and dynamic performance. Considerably, there are several methods to find the optimal locations of FACTS devices in the power system network (Singh and David, 2001) proposed a simple and efficient power flow performance index based model for optimizing the location of FACTS devices. The proposed model derived effective results for congestion management in power system network. FACTS controllers can be characterized into shunt controller, series controller and combined series shunt controller. The series controllers such as TCSC can lessen line loading and increase Available Transfer Capability (ATC) by controlling power flow in the power system network wherein the shunt controllers such as SVC are employed for voltage compensation and reactive power compensation. The combined series shunt can be implemented to release the congestion in power system, thereby increasing the voltage profile of the line network. Song *et al*. (2004) proposed various FACTS controllers and determined placement using optimizing techniques. The proposed model was tested under normal and line contingency situations. Yu and Lusan (2004) suggested a multiple time period welfare maximization model for installments of FACTS controllers. Karami and colleague have implied a model for optimal location of TCSC based on real power performance index, the results showed optimal location of TCSC can be determined by considering the sensitivity factor along with TCSC cost. Esmaili *et al*. (2014) proposed a multi objective modelfor locating series FACTS controllers by considering the Location Marginal Pricing (LMP) method. Thus, an optimal location of FACTS controllers improves the static and dynamic characters of power system network.

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Radically optimal placement of FACTS controllers involves a lot of non-linear variables often these variables are solved using optimization techniques.

Numerous optimization techniques have been suggested for pertinent location of FACTS controllers in power system network. The most often used are specified as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Gravitational Search Algorithm (GSA) and few other evolutionary algorithms (Granelli *et al*., 2006). Reddy *et al*. (2006) determined that optimal location of FACTS can eliminate transmission congestion in network. The researchers have used genetic algorithm for optimal location of FACTS controllers (Reddy *et al*., 2010) have proposed a multi objective optimization techniques for location and size of FACTS controllers, the researcher have GA and Strength Pareto Evolutionary Algorithm (SPEA). The implementation of FACTS controllers along with optimization techniques have become dominant in the present deregulated structure of power system network (Acharya and Mithulananthan, 2007).

This study focuses on multiple optimal locations of FACTS devices. The technique of multiple optimal location of FACTS device is patterned on Voltage Stability Index (VSI) and the proposed FFFA is used find multiple optimal location of FACTS controller by determining the optimal solution for the objective function framed by considering the VSI. The proposed scheme is implemented by employing two FACTS controllers namely TCSC and SVC at multiple optimal locations in IEEE 30 bus system. the effectiveness of the proposed algorithm is compared with other optimization techniques from literature (Benabid *et al*., 2009) to prove its validity.

Problem formulation: The optimal placement of FACTS controllers TCSC and SVC based on VSI which has been formulated as an optimization problem. The fitness function determined should be optimized for optimal placement of TCSC and SVC in the transmission network. The fitness function is given by Patel and Paliwal (2015):

$$\text{Min}\left[f\left(L_P\right)\right] = \sum_{i=1}^{n} T_L \tag{1}$$

Where:

- $f(L_p)$ = Power losses which is to be minimized in transmission lines
- n = Number of transmission lines
- T_L = Transmission losses

The objective function is defined for the minimal value for Eq. 1.

Performance metrics for problem defined: Power injection in a line can be calculated from the known values of bus voltage and current injected in each line. Thus, the line losses are the sum of power injection losses from both generation and load end. The equations are determined below:

$$T_{ij}^{P} = V_i I_{ij}^{*} \tag{2}$$

$$T_{ji}^{P} = V_j I_{ji}^{*} \tag{3}$$

$$T_{Lij}^{P} = S_{ij}^{P} + S_{ji}^{P} \tag{4}$$

Where:

- T_{ij}^{P} = Power injection from bus i to the line between bus i j
- T_i^{P} = Power injection from bus j to the line between bus i and j
- T_{lij}^{P} = Pwer loss in the line between bus i and j
- I_{ij}^{*} = Complex conjugate of current
- I_{ij}^{*} = Complex conjugate of current I_{ji}

The sum of the equations obtained is used as objective function for optimal location of TCSC and SVC in this proposed research work.

MATERIALS AND METHODS

Static modelling of TCSC and SVC

Modelling of SVC: The SVC is a shunt device of the FACTS family which is incorporated along with power electronics components to control power flow, thereby improving the transient stability on power grids. The output of the compensator is controlled in steps by sequentially switching of Thyristor Controlled Reactors (TCRs) and Thyristor Switched Capacitor (TSCs). By stepwise switching of reactors rather than continuous control, the need for harmonics filtering as part of the compensator scheme is eliminated. The parameters of the SVC has to be selected according to SVC rating and performance criteria taking into account the power system behaviour under various operating conditions (Bhattacharyya and Gupta, 2014; Table 1).

Simplified transfer function of SVC: The system stability studies narrate how to get the substantial results by means of SVC to stabilize system voltages. For this situation, the power system is represented by a source voltage in series with an equivalent system reactance X_e in p.u. Figure 1 shows a simplified block diagram of the SVC with closed loop terminal voltage control (Dixit *et al*., 2015). In the simplified model:

- H(s) transfer function of the voltage measuring device
- $G_R(s)$ transfer function of voltage regulator and slope unit

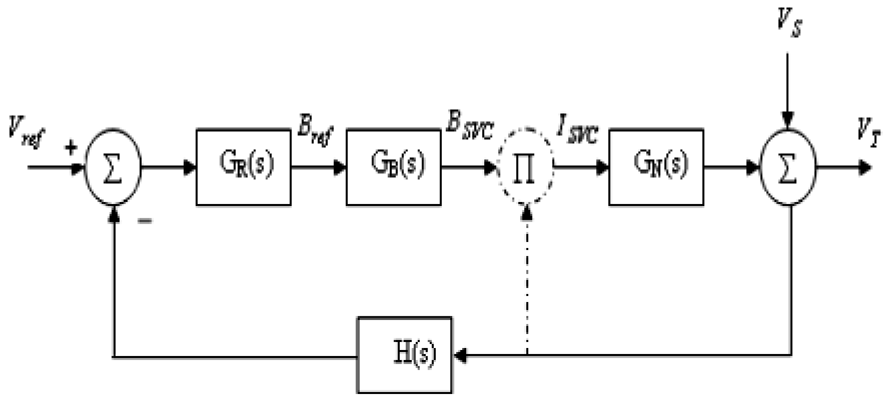

Fig. 1: Simplified block diagram model of SVC

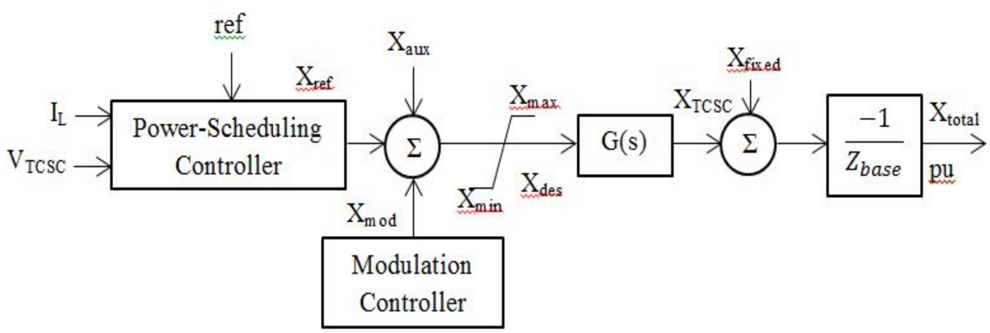

Fig. 2: Simplified block diagram model of TCSC

Table 1: Typical parameters for SVC models

Modules	Parameters	Definition	Typical value
Measuring	T_m	For time constant	0.001-0.005 sec
Thyristor control	T_d, T_b	Gating delay, firing delay	0.001, 0.003-0.006 sec
Voltage regulator	K_i	Integrator gain	K_i can be adjusted
Slope	X_{SL}	Steady state error	0.01-0.05 p.u

Table 2: Typical parameters for TCSC models

Modules	Parameters	Definition	Typical value
Measuring	T_m	For time constant	0.001-0.005s
Thyristor control	T_d T_b	Gating delay, firing delay	0.002 sec
0.003-0.006s			
Voltage regulator	K_i	Integrator gain	K_i can be adjusted
Slope	X_{SL}	Steady state error	0.02-0.06 p.u

- $G_B(s)$ transfer function of compensator main circuit
- $G_N(s)$ Transfer function of the network

The slope of the steady state characteristics is related to transfer function gain K_{SL}. For simplified model, the transfer function becomes:

$$\Delta V_T(s) = \frac{G_R(s)G_B(s)G_N(s)}{1+G_R(s)G_B(s)G_N(s)H(s)}\Delta V_{ref}(s) + \frac{1}{1+G_R(s)G_B(s)G_N(s)H(s)}\Delta V_s(s) \quad (5)$$

Modeling of TCSC: A TCSC involves continuous-time dynamics, relating to voltages and currents in the capacitor and reactor and nonlinear, discrete switching behavior of thyristor. Deriving an appropriate model for such a controller is an intricate task. A TCSC model for transient and oscillatory-stability studies is used widely for its simplicity and is the variable reactance model and the variation of the TCSC response with different firing angles are neglected. It is assumed that the transmission system operates in a sinusoidal steady state with the only dynamics associated with generators and Power System Stability (PSS). This assumption is valid because line dynamics much faster than the generator dynamics in frequency range of 0.1-2 Hz that are associated with angular-stability studies. Variable reactance TCSC model assumes the availability of a continuous-reactance range and is therefore applicable for multi module TCSC configurations. This model is generally used for inter-area model analysis and provides high accuracy when the reactance-boost factor (X_{TCSC}/X_c) is <1.5 (Saravanan *et al*., 2007). In Fig. 2, G(s) refers to the transfer function of compensator main circuit (Table 2).

Optimal allocation of TCSC and SVC: The VSI can be employed for allocation of FACTS controllers ie TCSC and SVC in transmission network. This can be incorporated by placing the TCSC and SVC accounting the weakest and heavily loaded bus in the line. The definitive value of VSI should be maintained in the range of 0-1. Thus, the mathematical formulation for VSI is given by Varma *et al*. (2014).

$$VSI_{ji} = \frac{2\sqrt{\left(X_{ji}^2 + R_{ji}^2\right)\cdot\left(P_{ji}^2 + Q_{ji}^2\right)}}{\left||E_i|^2 - 2X_{ji}Q_{ji} - 2R_{ji}P_{ji}\right|} \quad (6)$$

Where:

i = The sending bus
j = The receiving bus
X_{ji} = The reactance of the transmission line
R_{ji} = The resistance of the transmission line
P_{ji} = The real power at the receiving end of the line
Q_{ji} = The reactive power at the receiving end of the line

Conceptual overview of the proposed optimization technique

Fruit fly algorithm an overview: Fruit fly algorithm is a meta-heuristic algorithm inspired from the foraging behavior of fruit fly. The fruit fly has better olfactory organ to smell varieties of odor in the air and better visual sense. These characteristic features allow the fruit fly to locate nearby food and gather its position by visual perception and make it to fly towards the direction of the food. In accordance with these characteristics, the fruit fly algorithm has some necessary steps as follows:

- Set population size, maximum number of iterations and initialize location of fruit fly
- Initialize random direction and distance for individual fruit fly
- To calculate the new position's smell parameter estimate the reciprocal of distance between the old position and origin
- Determine the fitness function using smell parameter and find the maximal smell concentration (best individual)
- Using the best individual and location coordinates, the fruit fly will use vision to fly towards that location

These rules are used for iterations to find the optimal value of the objective function (Pan, 2012).

Firefly Algorithm (FFA) revisited: Firefly algorithm is a meta-heuristic algorithm inspired from behavior of fireflies swarm. This algorithm is based on attractiveness and light intensity. The firefly algorithm is made using the following assumptions:

- Fireflies are affected by the attractiveness and brightness as they are unisex
- The attractiveness increases as the brightness of the firefly increases and it decreases as the distance from each other increases
- The firefly moves in random when there is on brighter one
- The brightness of the firefly depends on the shape of the objective function (Yang, 2009)

These rules are used to get the optimal value of the objective function.

Proposed hybrid fruit fly-firefly algorithm: A hybrid fruit fly firefly algorithm is proposed in this study to solve the multi objective function. The proposed method is formed by the combination of sensing perception of fruit fly for faster exploration ability and bio lumine scence phenomenon of the firefly algorithm for increased exploitation ability. The fruit fly starts with the random location coordinates and the best individual moves to the next iteration. This process is repeated until the convergence is met and the obtained solution is the optimal solution. Similarly, the firefly algorithm starts with a set of random solution and move towards the optimal solution by allowing best solution to consequent iteration and eliminates the worst solution.

In this research, the initial values of firefly algorithm are the optimal solution obtained by the fruit fly algorithm. Due to this transfer of solution from fruit fly to firefly, the solution obtained by the hybrid approach will be better than fruit fly algorithm. The sequential steps involved in the proposed hybrid fruit fly-firefly algorithm are given below:

- The bus data, load flow data and line parameters data of each generating unit and system load is specified. The operating limits of the transmission line are specified
- The VSI factor to combine the multi objective problem is specified
- Using this factor and the power system data, initial conditions for power flow is specified
- With the obtained multi objective problem an AC power flow is carried out by initializing the conditions
- The various control parameters of the hybrid FFFA is set
- The fitness function is evaluated using multi-objective function

Table 3: Parameters and their values of evolutionary optimization algorithms

Approaches	Parametric values
GA parameters	
Population size	30.00
Crossover weight	0.60
Mutation rate	0.02
No. of generations	50.00
ACO parameters	
Number of ants	30.00
Probability of deterministic choice	0.98
Evaporation factor	0.20
No. of iterations	50.00
PSO parameters	
Number of particles	30.00
Number of iterations	50.00
Inertial weights	0.20
$C_1 = C_2$	0.10
Proposed FFFA parameters	
Number of fly	30.00
Abortion co-efficient	0.10
Maximum number of iteration	50.00
Location zone	[0-10.00]

- Using the location coordinates and best individuals, the fruit fly moves towards the food
- Then, using the new position, update the location coordinates and best individuals
- The best individuals of fruit fly algorithm act as the initial values of the FFFA
- Then, the FFA starts its search process by calculating the fitness function
- Using the fitness function, the best individual and location coordinates are calculated
- Steps 6-11 are repeated until stopping criterion (the maximum number of iterations) is met
- With this optimal solution the power flow in each line is computed with VSI factor and the optimal placement of the FACTS controllers are calculated for reducing the congestion in the heavily loaded transmission line

Progressive module of proposed FFFA technique: The proposed method is applied and tested on IEEE-30 bus test system. GA, ACO and PSO optimization technique is compared with the proposed FFFA. The parameters of the evolutionary optimization algorithms used for comparing FACTS controllers multiple optimal locations are listed in Table 3 (Singh and David, 2001). Considering the above parameters for the case study, following cases is discussed below. The four cases are mainly taken into condition for stimulating the real time voltage stability and line limits issues and also the four cases considered are mainly referred to check the co-ordination control of the two FACT controllers:

- Case-1; power flow analysisusing optimization techniques and without FACTS device
- Case-2; power flow analysis using optimization techniques and with FACTS device
- Case-3; power flow analysis with two TCSC and one SVC FACTS Device using optimization techniques
- Case-4; power flow analysis with two TCSC and one SVC FACTS device using optimization techniques

RESULTS AND DISCUSSION

The power flow calculations for IEEE 30 bus system without the FACTS controllers is tabulated in Table 4 and the MW line limits for 30 bus system is given in Table 5. From Table 4, it can be observed that line 5 and line 13 are the optimal place for allocating the FACTS controller as the line disobey the VSI and MW line limits.

The power flow calculations for IEEE 30 bus system with the FACTS controllers is tabulated in Table 6 for the line 5 and line 13. It is observed that line 5 and line 13 obey the VSI and MW line limits after the placement of FACTS controllers.

For the exertion of case 3, the maximum loaded line 5, line 6 and line 13 are chosen for optimal location of FACTS controllers. One TCSC and two SVC are taken into consideration. The analysis is tabulated in Table 7. For IEEE30 bus system.

The analysis of case 4 is carried out by calculating the power flow analysis with two TCSC and one SVC FACTS Device in line 5, 6 and 13. The results are incorporated in Table 8 for IEEE 30 bus system.

In Fig. 3, the objective function from Eq. 1 and 6 is taken and is solved using the proposed FFFA. A comparative line loading profile of IEEE 30 bus system is plotted with and without FACTS controllers. It is observed from the plot that the line loading percentage is decreased by using the FACTS controllers in the line.

From Table 4, its observed that line 5, 6 and 13 is overloaded in IEEE 30 bus system, hence, the objective function for optimal placement of FACTS controllers is solved using FFFA and one TCSC and two SVC are placed at optimal places in line. From Figure 4, it is inferred that the results prove decrease in line loading percentage, after considering the case 3 one TCSC and two SVC.

The case 4 is tested over for comparing the results of case 3 by interchanging the number of devices in line 5, 6 and 13 for IEEE 30 bus system by placingtwo TCSC and one SVC at the optimal locations. The results of IEEE 30 bus system for case 4 is shown in Fig. 5. The results represent a good VSI stability and further more improvement of voltage profile and enhanced loading capability for the lines as compared to case 3. This shows the co-ordination between multiple FACTS controllers further improve the stability of the system.

To validate the proposed FFFA, the objective function Eq. 1 and 6 is solved using other optimization

Table 4: Calculation of power flow and VSI for IEEE 30 bus system without FACTS devices

Line	i-j	Power flow (pu)	VSI
1	1-2	0.6428	1.122
2	1-3	0.9309	1.082
3	2-4	0.8224	1.092
4	3-4	0.7255	1.118
5	2-5	1.2383	0.752
6	2-6	0.9997	1.052
7	4-6	0.7064	1.119
8	5-7	0.0603	1.210
9	6-7	0.2994	1.138
10	6-8	0.3160	1.135
11	6-9	0.5078	1.128
12	6-10	0.2810	1.139
13	9-10	1.1771	0.862
14	4-12	0.4983	1.130
15	12-14	0.6202	1.123
16	12-15	0.3310	1.134
17	12-16	0.1714	1.165
18	14-15	0.2579	1.142
19	16-17	0.1584	1.187
20	15-18	0.1029	1.197
21	18-19	0.1779	1.160
22	19-20	0.1582	1.185
23	10-20	0.1221	1.194
24	10-17	0.1726	1.162
25	10-21	0.1986	1.152
26	10-22	0.2585	1.142
27	21-22	0.2653	1.141
28	15-23	0.2412	1.145
29	22-24	0.2034	1.150
30	23-24	0.1215	1.195
31	24-25	0.2099	1.147
32	25-27	0.1103	1.196
33	28-27	0.1940	1.151
34	27-29	0.0428	1.209
35	27-30	0.1415	1.175
36	29-30	0.2480	1.143
37	8-28	0.1443	1.170
38	6-28	0.1424	1.172
39	9-11	0.1122	1.196
40	12-13	0.3083	1.136
41	25-26	0.4734	1.131

Table 5: The MW line limits for IEEE 30 bus system

Line i-j	MW limit (pu)
1-2	0.70
1-3	0.80
2-4	0.80
3-4	0.80
2-5	0.50
2-6	0.80
4-6	0.72
5-7	0.56
6-7	0.40
6-8	0.35
6-9	0.52
6-10	0.30
9-10	0.52
4-12	0.52
12-14	0.70
12-15	0.35
12-16	0.25
14-15	0.25
16-17	0.15
15-18	0.12
18-19	0.20
19-20	0.25
10-20	0.25
10-17	0.25
10-21	0.25
10-22	0.25
21-22	0.25
15-23	0.25
22-24	0.25
23-24	0.12
24-25	0.48
25-27	0.12
28-27	0.52
27-29	0.12
27-30	0.15
29-30	0.25
8-28	0.25
6-28	0.25
9-11	0.52
12-13	0.52
25-26	0.12

Table 6: Computed power flow and VSI for IEEE 30 bus system with FACTS devicesin Line 5 and 13

Line	i-j	Power flow (pu)	VSI
1	1-2	0.64280	1.122
2	1-3	0.93090	1.082
3	2-4	0.82240	1.092
4	3-4	0.72550	1.118
5	2-5	0.92383	1.092
6	2-6	0.99970	1.052
7	4-6	0.70640	1.119
8	5-7	0.05930	1.219
9	6-7	0.29940	1.138
10	6-8	0.31600	1.135
11	6-9	0.50780	1.128
12	6-10	0.28100	1.139
13	9-10	0.97710	1.062
14	4-12	0.49830	1.130
15	12-14	0.62020	1.123
16	12-15	0.33100	1.134
17	12-16	0.17140	1.165
18	14-15	0.25790	1.142
19	16-17	0.15840	1.187
20	15-18	0.10290	1.197
21	18-19	0.17790	1.160
22	19-20	0.15820	1.185
23	10-20	0.12110	1.198
24	10-17	0.17060	1.168
25	10-21	0.19760	1.162
26	10-22	0.25750	1.148
27	21-22	0.26530	1.141
28	15-23	0.24120	1.145
29	22-24	0.20340	1.150
30	23-24	0.12150	1.195
31	24-25	0.20990	1.147
32	25-27	0.11030	1.196
33	28-27	0.19400	1.151
34	27-29	0.04280	1.209
35	27-30	0.14150	1.175
36	29-30	0.24800	1.143
37	8-28	0.14430	1.170
38	6-28	0.14240	1.172
39	9-11	0.11220	1.196
40	12-13	0.30830	1.136
41	25-26	0.47340	1.131

Table 7: Computed power flow and VSI for IEEE 30 bus system one TCSC in line 5,Two SVC line 13 and 6

Line	i-j	Power flow (pu)	VSI
1	1-2	0.64280	1.122
2	1-3	0.93090	1.082
3	2-4	0.82240	1.092
4	3-4	0.72550	1.118
5	2-5	0.92383	1.092
6	2-6	0.85990	1.097
7	4-6	0.70540	1.122
8	5-7	0.05930	1.219
9	6-7	0.29840	1.140
10	6-8	0.31580	1.137
11	6-9	0.50580	1.130
12	6-10	0.28000	1.139
13	9-10	0.97710	1.062
14	4-12	0.49830	1.130
15	12-14	0.62020	1.123
16	12-15	0.33100	1.134
17	12-16	0.17140	1.165
18	14-15	0.25790	1.142
19	16-17	0.15840	1.187
20	15-18	0.10290	1.197
21	18-19	0.17790	1.160
22	19-20	0.15820	1.185
23	10-20	0.12110	1.198
24	10-17	0.17060	1.168
25	10-21	0.19760	1.162
26	10-22	0.25750	1.148
27	21-22	0.26530	1.141
28	15-23	0.24120	1.145
29	22-24	0.20340	1.150
30	23-24	0.12150	1.195
31	24-25	0.20990	1.147
32	25-27	0.11030	1.196
33	28-27	0.19400	1.151
34	27-29	0.04280	1.209
35	27-30	0.14150	1.175
36	29-30	0.24800	1.143
37	8-28	0.14430	1.170
38	6-28	0.14240	1.172
39	9-11	0.11220	1.196
40	12-13	0.30830	1.136
41	25-26	0.47340	1.131

Table 8: Computed power flow and VSI for IEEE 30 bus system Two TCSC in line 5 and 6 and one SVC line 13

Line	i-j	Power flow (pu)	VSI
1	1-2	0.64280	1.122
2	1-3	0.93090	1.082
3	2-4	0.62240	1.132
4	3-4	0.72550	1.118
5	2-5	0.62383	1.139
6	2-6	0.69970	1.152
7	4-6	0.70640	1.119
8	5-7	0.05930	1.219
9	6-7	0.29940	1.138
10	6-8	0.31600	1.135
11	6-9	0.50780	1.128
12	6-10	0.28100	1.139
13	9-10	0.67710	1.162
14	4-12	0.49830	1.130
15	12-14	0.62020	1.123
16	12-15	0.33100	1.134
17	12-16	0.17140	1.165
18	14-15	0.25790	1.142
19	16-17	0.15840	1.187
20	15-18	0.10290	1.197
21	18-19	0.17790	1.160
22	19-20	0.15820	1.185

Table 8: Continue

Line	i-j	Power flow (pu)	VSI
23	10-20	0.12110	1.198
24	10-17	0.17060	1.168
25	10-21	0.19760	1.162
26	10-22	0.25750	1.148
27	21-22	0.26530	1.141
28	15-23	0.24120	1.145
29	22-24	0.20340	1.150
30	23-24	0.12150	1.195
31	24-25	0.20990	1.147
32	25-27	0.11030	1.196
33	28-27	0.19400	1.151
34	27-29	0.04280	1.209
35	27-30	0.14150	1.175
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37	8-28	0.14430	1.170
38	6-28	0.14240	1.172
39	9-11	0.11220	1.196
40	12-13	0.30830	1.136
41	25-26	0.47340	1.131

Table 9: Comparative analysis of line loading with existing and proposed optimization approach

Optimal location of FACTS controller	Optimization technique used	Average line loading profile
SVC (Dixit *et al*., 2015)	GA	95.71
SVC (Lei *et al*., 2001)	ACO	90.32
SVC& TCSC (Saravanan *et al*., 2007)	PSO	85.19
Proposed Approach SVC and TCSC	FFFA	80.65

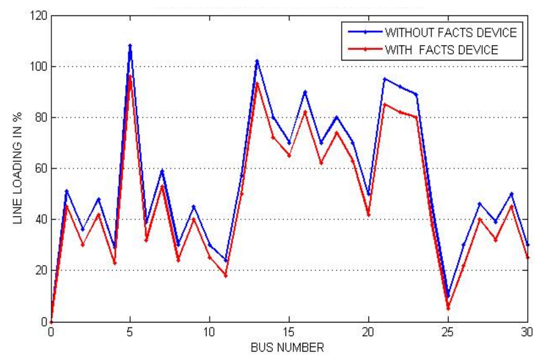

Fig. 3: Line loading profile with and without FACTS device for IEEE 30 bus

techniques and the line loading of IEEE 30 bus system with FACTS controllers is observed as shown in Fig. 6, the algorithms taken for validation include PSO, ACO and GA. The figures discloses the line loading for other algorithms and the proposed FFFA, it shows line loading percentage of FFFA is comparatively lesser than the existing optimization algorithms for the above cases considered and the average line loading profile for IEEE 30 bus system observed from Fig. 6 is tabulated in Table 9.

The convergence characteristics are shown in Fig. 7, respectively. The FFFA has efficient convergence in comparison with the other techniques considered while

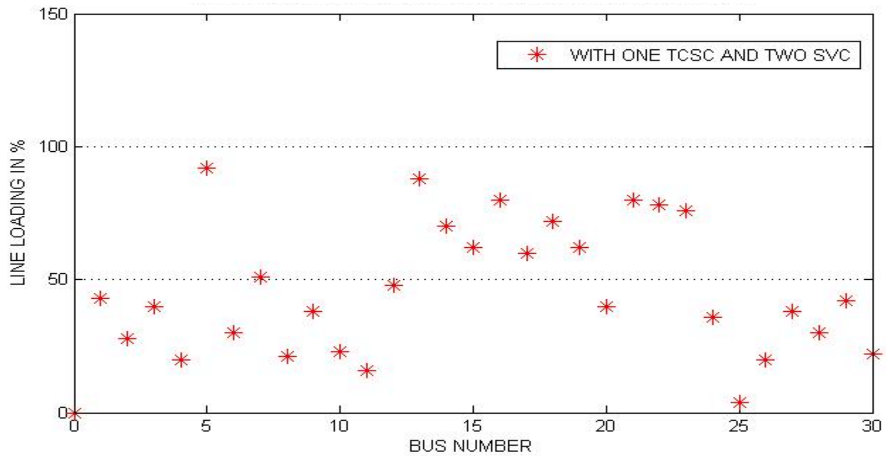

Fig. 4: Line loading profile with FACTS device for case 3 in IEEE 30 bus

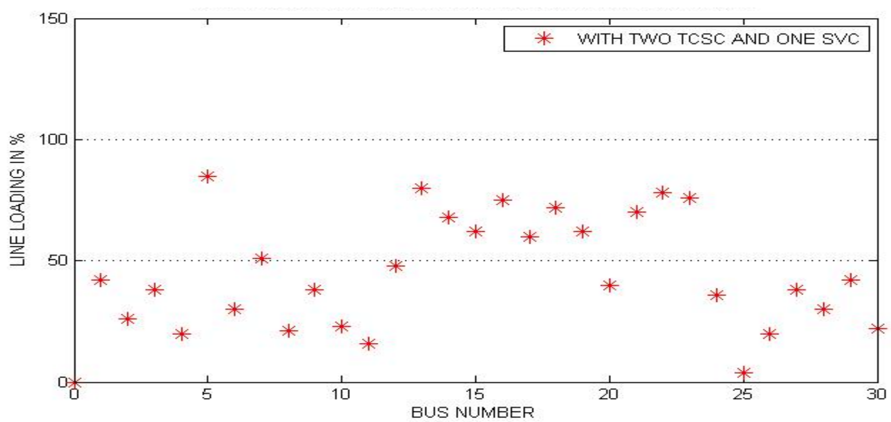

Fig. 5: Line loading profile with FACTS device for case 4 in IEEE 30 bus

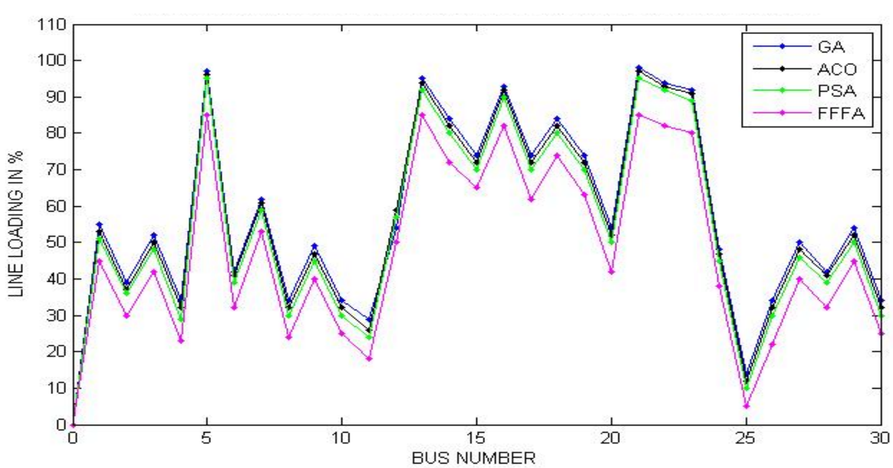

Fig. 6: Line loading profile with different optimization techniques in IEEE 30 bus

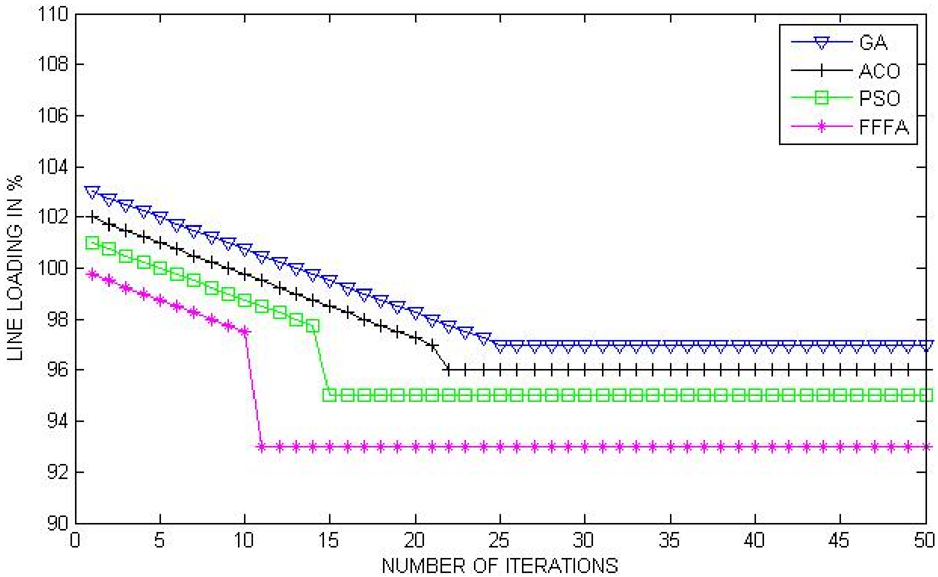

Fig. 7: Line loading profile with respect to convergence rate for IEEE 14 bus

solving the multi objective function from Eq. 1 and 6 for the given transmission line. It is found FFFA outperforms with a good convergence characteristics when location zone is in the range of [0-10].

Hence, for all the test cases considered on IEEE 30 bus system, the proposed FFFA method to solve the objective function shows better results with reduced line loading and improved VSI stability.

CONCLUSION

In this study, a multi objective function isdefinedto find the optimal location of TCSC and SVC as FACTS controllers. The optimal placement is scaled based on optimal power flowas well as VSI factor. The multi objective function depicted for finding optimal placement of FACTS controller is solved using the proposedhybrid FFFA optimization technique.

Analysis is carried out by taking four cases in IEEE 30 bus system.With the simulated output and results, it is proved that the proposed scheme has reduced the line loading of the bus system, thereby increasing the voltage stabilityin the network. The above method is tested on IEEE30 bus system and it can be extended to any practical network.

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