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Application of shuffled BAT algorithm for optimal sizing and location of thyristor controlled series compensator

Venugopal D*and Jaya Laxmi A**

This paper presents an algorithm for optimal placement and size of the series FACTS device considering branch loading, voltage profile improvement and loss minimization as multi objectives. FACTS device studies and for every combination indices branch loading, voltage profiles are studied. To optimize the objective function new optimization technique called shuffled bat algorithm is proposed. The work is tested on IEEE-30 bus system with different % of loading such as 90,100 and 110% of base load condition. With shuffled bat algorithm, the voltage profile of the system and branch loading with different loading conditions are presented. The performance of the proposed algorithm is compared with conventional sensitivity based optimization method and presented for illustration purpose.

Keywords: *Flexible AC Transmission Systems (FACTS), Thyristor Controlled Series Compensator (TCSC), BAT Algorithm (BAT), Shuffled Frog Leap Algorithm (SFLA).*

1.0 INTRODUCTION

Power system operation poses the greatest challenge to a competitive environment incorporating open transmission access. Open access implies that the opportunity to use the transmission system must be equally available to all buyers and sellers. This is an important step to promote electricity supply system deregulation. Managing dispatch in an open access environment is a new challenge facing transmission system operators who are mandated to provide a level playing field for all transmission users. The issue of transmission congestion management is especially important. Transmission networks are one of the main sources of difficulties on fair implementation of electricity restructuring. The limitations of a power transmission network arising from environmental, right-of-way and cost problems are fundamental to both bundled and unbundled power systems.

Reactive power and voltage control plays an important role in supporting the real power transfer across a large-scale transmission system [1]. The local nature of the reactive power also implies that the generator may provide the reactive power support for a number of transactions even if that particular generator is not involved in the real power dispatch. The allocated contributions of the individual generator's reactive power output to a particular transaction can be negative or positive [2]. Reactive support is generally provided by the switching of shunt reactors, the positioning of transformer taps and the reactive power outputs of generators. Thus, the Var support requirement from generators and capacitors to manage congestion along with real power rescheduling poses a great challenge to SO in an open-access electricity market.

Appearance of FACTS devices (*Flexible AC Transmission Systems*) opens up new opportunities for controlling power and enhancing the usable

* Department of EEE, Kamala Institute of Technology & Science, Singapur, Karimnagar, India, venufacts20m@gmail.com
**Department of EEE, JNTUH College of Engineering, Hyderabad, India, ajl1994@yahoo.co.in

capacity of existing transmission lines. Studies and realizations have shown their capabilities in steady-state or dynamic stability [3]-[4]. With their ability to change the apparent impedance of a transmission line, FACTS devices may be used for active power control, as well as reactive power or voltage control. In the paper[5] presented Genetic Algorithm to seek the optimal location of multi-type FACTS devices in power systems. In this, location, type and rated values of FACTS devices are optimized simultaneously. Locations of FACTS devices in power system are obtained on the basis of static and dynamic performance. H.Ambriz-Perez et.al, [6] has been presented SVC load flow models using total susceptance and firing angle methods. In 2004, Sang-Hwan Song et al. [7] presented steady state security index for contingency analysis of the power system, which indicates the security of each contingency to determine the optimal location of SVC and UPFC. From late 1970s onwards SVC has been effectively used in power system to provide a fast and reliable control of production or absorption of reactive power and for control of voltage at weak points in the network. SVC normally includes a combination of mechanically controlled and thyristor controlled shunt capacitors and reactors [8]. H.Ambriz et al. [8] proposed SVC models for NR Load flow and Newton optimal power flow solutions.SVC consists of a group of shunt connected capacitors and reactor [8] banks with fast control action achieved by means of thyristor control. The most commonly used configuration for continuously controlled SVC's is the combination of either fixed capacitor and thyristor controlled reactor (FC-TCR) or thyristor switched capacitor and thyristor controlled reactor. The paper presents, SVC susceptance and firing angle models for power flow and OPF solutions. Both the models modify the corresponding Jacobian matrix elements at the SVC bus.

Only the SVC susceptance model has been presented in [9]. Insertion of FACTS devices is found to be highly effective in preventing voltage instability and minimize the active or real power loss on transmission lines [10].Series and shunt compensating devices are used to enhance the static voltage stability margin and reduce the real power loss appreciably [11].In [12] it is proposed the design and application of coordinated multi type FACTS controllers. The SVC is modeled as a variable susceptance reactive power source/sink at the connected bus.

Various impact indices are studied in this paper. The indices are developed in view of improving the system performance by increasing the line loading and improve the voltage profile of the network. For finding the optimal sizing and optimal location by minimizing the impact indices, a new shuffled bat algorithm is used. Shuffled bat algorithm is a real coded population based meta heuristic optimization method that is formed by combining the properties of shuffled frog leap algorithm and bat algorithm. The exploitation quality of the SFLA and exploration quality of bat algorithms is combined to form a new optimization algorithm. The proposed Shuffled bat algorithm is demonstrated on IEEE 30 bus system and performance is compared with conventional optimization technique like sensitivity method and satisfactory results are obtained.

2.0 IMPACT INDICES AND OBJECTIVE FUNCTION

The objective of optimal location of FACTS devices on the Transmission system is to minimize congestion on the transmission system thus minimizing pre specified parameters like Branch loading and/or Voltage levels, power losses.

The equation related to these parameters are given by,

(1) Branch loading ($f_1(x)$)

$$J_1(\text{BL}) = \prod_{line} \cdot J_{line}$$

$$J_{line} = \begin{cases} 1, & S_{pq}^{max} > S_{pq} \\ e^{\lambda\left(1-\frac{S_{pq}}{S_{pq}^{max}}\right)}, & S_{pq} > S_{pq}^{max} \end{cases} \quad ...(1)$$

More power is transmitted by the network to the consumers keeping power system in a secure state in terms of branch loading and this gives the information about the line of MVA flow through the transmission network regarding the maximum capacity of conductors. It gives the higher flow deviation of the line from the MVA capacity of line, therefore makes the uniform line flows in the system without congestion.

(2) Voltage levels ($f_2(x)$)

$$J_2=\prod_{bus} \cdot V_{s_{bus}}$$

$$V_s = \begin{cases} 1, & 0.9 \leq V_b \leq 1.1 \\ exp^{\mu(1-V_b)}, & other\ wise \end{cases} \quad ...(2)$$

It favours bus voltages close to 1p.u. It depends on the proper location and size of the FACTS devices.

(3) Loss Minimization(LM)[$f_3(x)$]

Transmission line power loss in each branch is calculated from the load flow solution. Net system power loss is the sum of power losses in each line.

$$J_2=\sum_{i=1}^{NL} loss_i \quad ...(3)$$

2.1 Objective Function

The main objective of the paper is to study the effect of placing and sizing the FACTS devices in all system indices given earlier. Multi objective optimization is formed by combining the all indices with appropriate weights. The multi objective function is defined as

$$F=\min \{W1\ f1(x) + W2\ f2(x) + W3\ f3(x)\} \quad ...(4)$$

To convert multi objective function into single objective, weights are added. Weights are adjusted by trial and error method and by taking into account constraint.

Where Wk € [0, 1] $\sum_{k=1}^{3} Wk=1$ ...(5)

The weights are indicated to give the corresponding importance to each impact indices for the placement of FACTS device and depend on the required analysis. In this analysis branch loading have higher weight (0.6), since the main importance is to reduce congestion of transmission network. The objective function is to minimize with equality and inequality constraints.

Equality constraints

Load Flow Constraints

$$P_{Gi} - P_{Di} - \sum_{j=1}^{NB} |Vi|\ |Vj|\ |Yij| \cos(\delta_i - \delta_j - \theta_{ij})=0 \quad (5.1)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{NB} |Vi|\ |Vj|\ |Yij| \sin(\delta_i - \delta_j - \theta_{ij})=0 \quad (5.2)$$

Where,

P_{Gi} = Real power generated at bus i

P_{Di} = Real power demand at bus i

Q_{Gi} = Reactive power generated at bus i

Q_{Di} = ReactivePower demend at bus i

V_i =Voltage magnitude at bus i

V_j= Voltage magnitude at bus j

Y_{ij} = Admittance of line conductor between bus I and j

δ_i = Angle of bus voltage at bus i

δ_j = Angle of bus voltage at bus j

θ_{ij}= Angle of admittance between buses i and j

Inequality Constraints

Reactive Power Generation Limit of SVCs

$Q_{SVCi}^{min} \leq Q_{SVCi} \leq Q_{SVCi}^{max}$; iϵ N_{SVC} (5.3)

Reactance Limits of TCSCs

$-0.8X_{ij} \leq X_{TCSC\,k} \leq 0.2X_{ij}$; kϵ N_{TCSC} (5.4)

Voltage Constraints

$V_i^{min} \leq V_i \leq V_i^{max}$; iϵ N_B (5.5)

Transmission line flow limit

$S_i \leq S_i^{max}$; iϵ N_L (5.6)

Where

Q_{SVCi}=Reactive power generation of i^{th} SVC (i=1,2,…N_{SVC})

N_{SVC} = Number of SVCs connected to the system

$X_{TCSC\,k}$= Reactance of k^{th} TCSC (k=1,2,…..N_{TCSC})

N_{TCSC}= Number of TCSC connected to the system

V_i =Voltage magnitude of bus i (i=1,2,…. N_B)

S_i=Transmission line flow of the i^{th} line (i=1,2…. N_L)

3.0 CONGESTION MANAGEMENT BY OPTIMAL PLACEMENT OF FACTS DEVICES USING SENSITIVITY METHOD

The power flows are computed for the selected bus system in choice. Then the line suffering from congestion has been finding out in the system. The values of the sensitivity factors are calculated for the selected bus system.

3.1 Reduction of total system VAR power loss

Here, we look at a method [13] based on sensitivity of the total system reactive power loss with respect to the control variable of the TCSC. For TCSC to be placed in between buses i and j, we consider net line series reactance as a control parameter. By differentiating the reactive power loss Q_L with respect to control parameter of TCSC we can obtain the sensitivity factor a_{ij}. Loss sensitivity with respect to control parameter of TCSC placed between buses i and j can be written as

$$a_{ij} = \frac{\partial Q_L}{\partial x_{ij}} = \left[V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij}\right].(r_{ij}^2 - x_{ij}^2)/(r_{ij}^2 + x_{ij}^2)^2 \quad \text{...(6)}$$

3.2 Real power flow performance index sensitivity indices

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index [14], as given below

$$PI = \sum_{m=1}^{N_1} \frac{w_m}{2n}\left(\frac{P_{Lm}}{P_{Lm}^{max}}\right)^{2n} \quad \text{...(7)}$$

Where P_{LM} the real power is flow and P_{Lm}^{max} is the rated capacity of the line-m, N is the exponent and w_m is a real non-negative weighting coefficient which may be used to reflect the importance of the lines.

PI will be small when all the lines are within their limits and reach a high value when there are overloads. Thus, it provides a good measure of severity of the line overloads for given state of the power system. The real power flow PI sensitivity factors with respect to the parameters of TCSC can be defined as

$$b_k = \frac{\partial PI}{\partial x_{ck}} \text{ at } x_{ck} = 0 \quad \text{...(8)}$$

The sensitivity of PI with respect to TCSC parameter connected between bus-i and bus-j can be written as

$$\frac{\partial PI}{\partial x_k} = \sum_{m=1}^{N_L} Wm\, P_{Lm}^3 \left(\frac{1}{P_{Lm}^{max}}\right)^4 \frac{\partial P_{Lm}}{\partial x_k} \quad \text{...(9)}$$

Where

$$\frac{\partial P_{Lm}}{\partial x_{ck}} = \begin{cases} S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mj}\frac{\partial P_j}{\partial x_{ck}}, & m \neq k \\ S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mj}\frac{\partial P_j}{\partial x_{ck}} + \frac{\partial P_j}{\partial x_{ck}}, & m = k \end{cases} \quad \text{...(10)}$$

Where

$$\frac{\partial P_i}{\partial x_{ck}} = -2\left(V_i^2 - V_iV_j\cos\delta_{ij}\right)\frac{r_{ij}x_{ij}}{(r_{ij}^2+x_{ij}^2)^2} - V_iV_j\sin\delta_{ij}\frac{(x_{ij}^2-r_{ij}^2)}{(r_{ij}^2+x_{ij}^2)^2} \quad (11)$$

$$\frac{\partial P_j}{\partial x_{ck}} = -2\left(V_j^2 - V_iV_j\cos\delta_{ij}\right)\frac{r_{ij}x_{ij}}{(r_{ij}^2+x_{ij}^2)^2} + V_iV_j\sin\delta_{ij}\frac{(x_{ij}^2-r_{ij}^2)}{(r_{ij}^2+x_{ij}^2)^2} \quad (12)$$

3.3 Reduction of total system Active power loss

Here, we look at a method based on sensitivity of the total system active power loss with respect to the control variable of the TCSC. Loss sensitivity with respect to control parameter of TCSC placed between buses i and j can be written as follows:

The active power loss in the line having TCSC can be written as

$$P_L = P_{ii} + P_{ii} = G_{ii}'(V_i^2 + V_i^2) - 2V_iV_iG_{ii}'\cos\delta_{ii} \quad \text{...(13)}$$

Now by differentiating the equation (13) with respect to control parameter of TCSC we will obtain the sensitivity factor c_{ij}, which is as follows:

$$c_{ij} = \frac{\partial P_L}{\partial x_{ij}} = \left[V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij}\right].(-2r_{ij}x_{ij})/(r_{ij}^2 + x_{ij}^2)^2$$

Based upon the sensitivity factors proper line is chosen for the TCSC placement. The sensitivity method providing the less cost for our selected bus system is considered as the most economic and appropriate method for relieving congestion in the system. The reactive power reduction method has been named as method 1, the PI reduction method is named as method 2 and the active power loss reduction method is named as method 3. It is the proposed method. All these three methods are discussed for the IEEE 30 bus system. The slack bus is numbered as 1 followed by the generating buses and load buses.

3.4 Shuffled Bat Algorithm

3.4.1 Shuffled Frog Leap Algorithm (SFLA)

The SFLA is a real coded population based heuristic algorithm formed by mimetic evolution of a group of frogs searching for an area where the maximum amount of food is available. It is based on the evolution of memes carried by the interactive individuals and a global exchange of information among themselves [15].In essence, it combines the benefits of local search tool of the PSO [16] and mixing the information from parallel local searches to move toward a global solution [17].In the SFLA, the population consists of a set of frogs [18] with the same structure of PSO but different adaptabilities. Each frog represents the feasible solution to optimization problem and it is partitioned into subsets referred to as memeplexes. The different memeplexes are considered as different cultures of frogs, each performing a local search.

3.4.2 Bat Algorithm

Bat Algorithm is a real coded population based heuristic method that mimics the mimetic evolution of a group of bats when seeking for the location that has the maximum amount of food. The echolocations of micro bats are the feasible solutions. It is based on frequency tuning technique to control the dynamic behaviour of a swarm of bats, i.e evolution of group of bats carried by the interactive individuals and global exchange of information among themselves[19]. In the Bat Algorithm, the population consists of a set of Bats with same structure as PSO but different adaptabilities. Virtual bat flies randomly with a velocity (V_i) at position (solution) (X_i) with a varying frequency or wavelength and loudness (A).As it searches and finds its prey, it changes frequency, loudness (A) and pulse rate(r) [20].

3.4.3 Shuffled Bat Algorithm (ShBat)

The shuffled Bat algorithm (ShBat) is a real coded population based Meta heuristic optimization method which is newly formed by combing the properties of SFLA [15] and BAT [20].The exploitation property of the SFLA and exploration of BAT algorithms are combined to form a new optimization algorithm. It is a randomly real coded used for population generation for starting and divides the bat population into memeplexes with all memeplexes into single population and check for convergence with maximum number of iterations. The next generation of population is same as Bat algorithm and dividing the next generation population into memeplexes to continue the process. The convergence criterion is taken from SFLA and for better convergence the shuffling process is very useful.

4.0 MODELING OF FACTS DEVICES IN LOAD FLOW STUDIES

4.1 Static Representation of TCSC

The basic idea behind power flow control with the TCSC is to decrease or increase the overall lines effective series transmission impedance, by adding a capacitive or inductive reactance correspondingly [16]. The TCSC is modelled as variable impedance, where the equivalent reactance of the line x_{ij} is defined as:

$$Xij=X_{line}+XTCSC \tag{14}$$

Where, x_{line} is the transmission line reactance [12]. The equivalent reactance of line X_{ij} is defined as:

$$Xij=-0.8Xline \leq XTCSC \leq 0.2Xline \tag{15}$$

The level of applied compensation of the TCSC usually varies between 20% inductive and 80% capacitive. Figure 2 shows a controllable reactance ($-jx_{TCSC}$) placed in the transmission line connected between bus-i and bus-j.

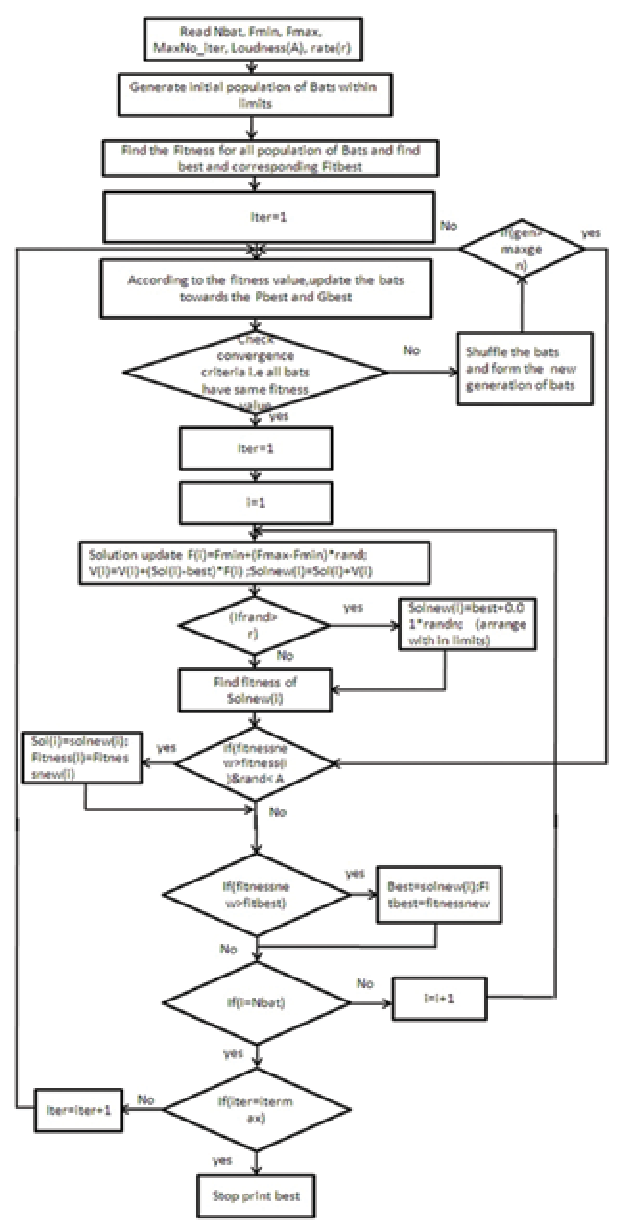

FIG.1 OPTIMAL PLACEMENT AND SIZING OF FACTS DEVICE USING SHUFFLED BAT ALGORITHM

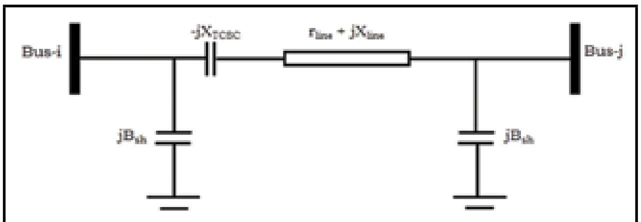

FIG. 2 EQUIVALENT CIRCUIT OF TCSC.

The real and reactive power flows from bus-i to bus-j and bus-j to bus-i in the line can be written as (1) to (4) with modified g_{ij} and b_{ij} as given below.

$$g_{ij} = \frac{r_{ij}}{r_{ij}^2+(x_{ij}-x_{TCSC})^2} \;,\; b_{ij} = \frac{-(x_{ij}-x_{TCSC})}{r_{ij}^2+(x_{ij}-x_{TCSC})^2}$$

The TCSC (*Thyristor Controlled Series Capacitor*), which permits to modify the reactance of the line X_{12}.The model of the FACTS device, was developed to be suitable for steady-state. Each device may take a fixed number of discrete values. The TCSC may have one of the two possible characteristics: capacitive or inductive, respectively to decrease or increase the reactance of the line X_L. It is modelled with three ideal switched elements in parallel: a capacitance, an inductance and a simple wire, which permits the TCSC to have the value zero. The capacitance and the inductance are variable and their values are function of the reactance of the line in which the device is located.

In order to avoid resonance, only one of the three elements can be switched at a time. Moreover, to not overcompensate the line, the maximum value of the capacitance is fixed at $-0.8X_L$. For the inductance, the maximum is $0.2\ X_L$.

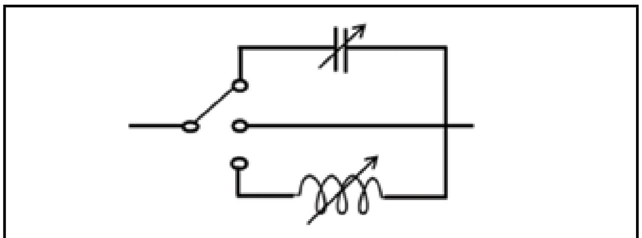

FIG. 3 MODEL OF TCSC

4.2 Model of Transmission line with TCSC

The model of transmission line with a TCSC connected between bus-i and bus-j is shown in Figure 4. During the steady state the TCSC can be considered as a static reactance $-jx_c$. The real and reactive power flow from bus-i to bus-j and from bus-j to bus-i of a line having series impedance and a series reactance are

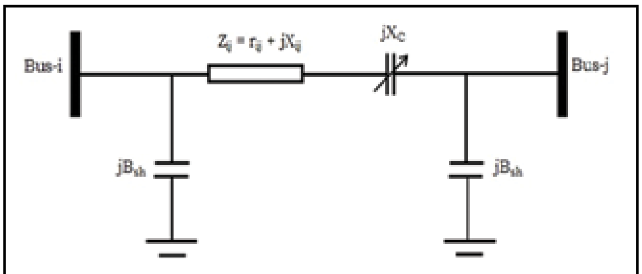

FIG. 4 MODEL OF TRANSMISSION LINE WITH TCSC

$$P_{ij}^{c} = V_i^2 G_{ij}^{'} - V_i V_j [G_{ij}^{'} \cos\delta_{ij} + B_{ij}^{'} \sin\delta_{ij}] \quad (16.1)$$

$$Q_{ij}^{c} = -V_i^2 (B_{ij}^{'} + B_{sh}) - V_i V_j [G_{ij}^{'} \sin\delta_{ij} - B_{ij}^{'} \cos\delta_{ij}] \quad (16.2)$$

$$P_{ji}^{c} = V_j^2 G_{ij}^{'} - V_i V_j [G_{ij}^{'} \cos\delta_{ij} - B_{ij}^{'} \sin\delta_{ij}] \quad (16.3)$$

$$Q_{ij}^{c} = -V_j^2 (B_{ij}^{'} + B_{sh}) + V_i V_j [G_{ij}^{'} \sin\delta_{ij} + B_{ij}^{'} \cos\delta_{ij}] \quad (16.4)$$

The active and reactive power loss in the line having TCSC can be written as

$$P_L = P_{ij} + P_{ji} = G_{ij}^{'}(V_i^2 + V_j^2) - 2V_i V_j G_{ij}^{'} \cos\delta_{ij} \quad (17.1)$$

$$Q_L = Q_{ij} + Q_{ji} = -(V_i^2 + V_j^2)(B_{ij}^{'} + B_{sh}) + 2V_i V_j B_{ij}^{'} \cos\delta_{ij} \quad (17.2)$$

$$\text{Where,} G_{ij}^{'} = r_{ij}/(r_{ij}^2 + (x_{ij} - x_c)^2)$$

$$B_{ij}^{'} = -(x_{ij} - x_c)/(r_{ij}^2 + (x_{ij} - x_c)^2)$$

5.0 RESULTS AND DISCUSSION

The load flow of 30-bus system is shown in Table 1. In case of 30-bus system there are two congested lines. Those are line 1 (between 1-2) and line 6 (between 2-9). From the load flow it was found that real power flow in line 1(between 1-2) was 1.1248 p.u. and the real power flow in line 6 (between 2-9) was 1.046 p.u. which are more than the line loading limit.

The sensitivities of reactive power loss reduction, real power flow performance index and active power loss reduction with respect to TCSC control parameter has been computed and shown in Table 2. The sensitive line in each case is presented in bold type. It can be observed from Table.2 (column 3) that placement of TCSC in line-20 is suitable for reducing the total reactive power loss. The value of power flow in the congested line-1 after placing TCSC is 0.9987p.u and the value of line flow in line-6 is 0.9568p.u as shown in Table 2. It can be observed that congestion has been relieved has been relieved in the system after placing the TCSC. The value of Control parameter of TCSC for computing power flow is taken as 0.17885p.u.

It can be observed from Table.2 (column 4) that placing a TCSC in line-4 is optimal for reducing the PI and congestion relief. Power flow Value of the congested line-1 after placing TCSC in line-4 is 0.9984 p.u and the value of line flow in line-6 is 0.9476 p.u as shown in Table 3. The value of Control parameter of TCSC for computing power flow is taken as 0.0326p.u. It can be observed that congestion has been relieved. From the Table.2 (column 5) it can be observed that placing a TCSC in line-36 is optimal for reducing the Active power loss and for congestion relief. Power flow Value of the congested line-1 after placing TCSC in line-36 is 0.9876 p.u and the value of line flow in line-6 is 0.9321 p.u. as shown in Table 3. The value of Control parameter of TCSC for computing power flow is taken as 0.2356p.u. It can be observed that congestion has been relieved.

Placement of TCSC in line-4 will reduce the PI value and placement of TCSC in line-20 may reduce the reactive power loss but it will be less effective than placing a TCSC in line-36 as can be seen from its sensitivity factors. Voltage magnitude values obtained from various methods are shown in Table.4. It can be observed from results that reduction of total system active power loss method is more economical than VAR power loss method and PI method for placing the TCSC and congestion management. The Voltage Profile for the 30-bus system obtained from the sensitivity analysis of cij is shown the Figure 5.

TABLE 1

POWER FLOW RESULT FOR 30-BUS SYSTEM BEFORE PLACEMENT OF TCSC

LINE	I-J	POWER FLOWS
1	**1-2**	**1.2748**
2	1-7	0.8061
3	2-8	0.4810
4	7-8	0.7014
5	2-3	0.6221
6	**2-9**	**1.046**
7	8-9	0.6547
8	3-10	0.0822
9	9-10	0.1476
10	9-4	-0.0355
11	9-11	0.4956
12	9-12	0.2071
13	11-5	0.0695
14	11-12	0.1253
15	8-13	0.4215
16	13-6	-0.2399
17	13-14	0.0909

18	13-15	0.2254
19	13-16	0.1323
20	14-15	0.0280
21	16-17	0.0958
22	15-18	0.0952
23	18-19	0.0617
24	19-20	-0.0320
25	12-20	0.0559
26	12-17	-0.0052
27	12-21	0.1332
28	12-22	0.0605
29	21-22	-0.0403
30	15-23	0.0733
31	22-24	0.0172
32	23-24	0.0402
33	24-25	-0.0302
34	25-26	0.0356
35	25-27	-0.0658
36	28-27	0.1996
37	27-29	0.0620
38	27-30	0.0710
39	29-30	0.0370
40	4-28	0.0536
41	9-28	0.1467

TABLE 2

SENSITIVITY INDICES FOR30-BUS SYSTEM

Line	i-j	a_{ij}	b_{ij}	c_{ij}
1	1-2	-0.0012	1.1352	-0.0023
2	1-7	-0.5181	-0.6546	-0.3065
3	2-8	-0.1755	-0.8522	-0.1291
4	7-8	-0.3965	**-0.8696**	-0.3143
5	2-3	-0.3331	-0.0650	-0.1681
6	2-9	-0.3028	0.0099	-0.2239
7	8-9	-0.4864	0.0001	-0.3048
8	3-10	-0.0151	-0.1674	-0.0142
9	9-10	-0.0282	-0.1678	-0.0205
10	9-4	-0.0924	-0.2237	-0.0575
11	9-11	-0.2399	0	-0.0026
12	9-12	-0.0423	-0.3252	-0.0037
13	11-5	-0.0468	0	-0.0043
14	11-12	-0.0341	-0.3270	-0.0024
15	8-13	-0.1850	1.0923	-0.0012
16	13-6	-0.1319	0.0169	-0.0032
17	13-14	-0.0052	-0.1687	-0.0065
18	13-15	-0.0319	-0.2155	-0.0437
19	13-16	-0.0112	-0.0872	-0.0138
20	14-15	**0.0001**	-0.2378	-0.0008
21	16-17	-0.0064	-0.2607	-0.0066
22	15-18	-0.0056	-0.0933	-0.0072
23	18-19	-0.0024	-0.2607	-0.0031
24	19-20	-0.0011	-0.0636	-0.0015
25	12-20	-0.0030	-0.0654	-0.0033
26	12-17	-0.0013	-0.2618	-0.0012
27	12-21	-0.0200	-0.5054	-0.0237
28	12-22	-0.0042	0.6215	-0.0054
29	21-22	-0.0010	0.6329	-0.0013
30	15-23	-0.0042	0.4660	-0.0056
31	22-24	-0.0016	-0.2532	-0.0035
32	23-24	-0.0014	-0.2505	-0.0018
33	24-25	-0.0006	0.0004	-0.0010
34	25-26	-0.0007	-0.1014	-0.0018
35	25-27	-0.0026	0.7824	-0.0038
36	28-27	-0.0425	0.7821	**0.0015**
37	27-29	-0.0024	-0.0678	-0.0035
38	27-30	-0.0030	-0.3048	-0.0045
39	29-30	-0.0008	-0.3071	-0.0012
40	4-28	-0.0051	-0.0003	-0.0036
41	9-28	-0.0184	0	-0.0113

TABLE 3

POWER FLOW RESULT FOR 30-BUS SYSTEM AFTER INSERTION OF TCSC BASED ON THE SENSITIVITY METHODS

LINE	I-J	POWER FLOW BASED ON METHOD1	POWER FLOW BASED ON METHOD2	POWER FLOW BASED ON METHOD3
1	1-2	0.9987	0.9984	0.9876
2	1-7	0.7670	0.7742	0.7637
3	2-8	0.4590	0.4630	0.4571
4	7-8	0.5851	0.6045	0.5763
5	2-3	0.5978	0.6023	0.5957
6	2-9	0.9568	0.9476	0.9321
7	8-9	0.5603	0.5764	0.5530
8	3-10	0.0741	0.0756	0.0735
9	9-10	0.1374	0.1393	0.1366
10	9-4	-0.0166	-0.0194	-0.0154
11	9-11	0.4752	0.4790	0.4735
12	9-12	0.2038	0.2044	0.2035
13	11-5	0.0667	0.0672	0.0664
14	11-12	0.1159	0.1176	0.1151
15	8-13	0.4073	0.4100	0.4061
16	13-6	-0.2256	-0.2282	-0.2244
17	13-14	0.0881	0.0886	0.0878
18	13-15	0.2116	0.2141	0.2104
19	13-16	0.1270	0.1280	0.1265
20	14-15	0.0273	0.0274	0.0272
21	16-17	0.0919	0.0926	0.0915
22	15-18	0.0919	0.0925	0.0916
23	18-19	0.0583	0.0589	0.0580

24	19-20	-0.0276	-0.0284	-0.0273
25	12-20	0.0534	0.0539	0.0532
26	12-17	-0.0060	-0.0059	-0.0061
27	12-21	0.1167	0.1196	0.1154
28	12-22	0.0565	0.0572	0.0562
29	21-22	-0.0308	-0.0323	-0.0301
30	15-23	0.0701	0.0707	0.0698
31	22-24	0.0153	0.0157	0.0152
32	23-24	0.0388	0.0391	0.0387
33	24-25	-0.0298	-0.0299	-0.0297
34	25-26	0.0348	0.0349	0.0347
35	25-27	-0.0635	-0.0639	-0.0633
36	28-27	0.1952	0.1960	0.1948
37	27-29	0.0608	0.0611	0.0607
38	27-30	0.0701	0.0703	0.0700
39	29-30	0.0364	0.0365	0.0364
40	4-28	0.0507	0.0513	0.0505
41	9-28	0.1296	0.1326	0.1282

TABLE 4

VOLTAGE MAGNITUDE VALUES OBTAINED FROM VARIOUS METHODS

LINE	METHOD 1	METHOD 2	METHOD 3
1	1.000	1.000	1.000
2	1.000	1.000	1.000
3	0.983	0.981	0.900
4	0.980	0.984	0.900
5	0.982	0.985	0.920
6	0.973	0.978	0.980
7	0.967	0.961	0.970
8	0.961	0.958	0.965
9	0.981	0.984	0.979
10	0.984	0.984	0.985
11	0.981	0.987	0.983
12	0.985	0.986	0.987
13	1.000	1.000	1.000
14	0.977	0.982	0.984
15	0.980	0.981	0.986
16	0.977	0.98	0.974
17	0.977	0.977	0.977
18	0.968	0.965	0.974
19	0.965	0.962	0.978
20	0.969	0.978	0.987
21	0.993	1.000	1.020
22	1.000	1.000	1.000
23	1.000	1.000	1.000
24	0.989	0.900	0.920
25	0.990	0.990	1.040
26	0.972	0.976	0.980
27	1.000	1.000	1.000
28	0.975	0.979	0.980
29	0.98	0.984	0.987
30	0.968	0.968	0.971

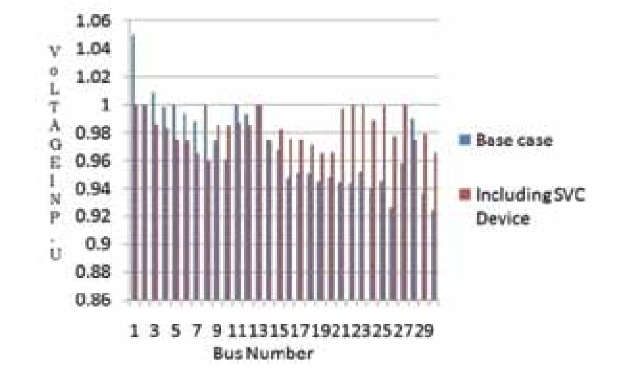

FIG. 5 VOLTAGE PROFILE OF SVC FACTS DEVICE WITH BAT ALGORITHM

In this paper meta heuristic method shuffled bat based optimization technique is used to find the optimal placement and sizing of FACTS devices by minimizing the branch loading and voltage deviations. The shuffled bat algorithm contains 40 bats. The Figure 1 shows the flow chart of optimal placement and sizing of the FACTS devices. MATLAB programming platform is used for simulation. Shuffled bat optimization algorithm is programmed to obtain objective function. Maximum number of iterations are limited to 40.In this study frequency limits are adjusted in between -1.0 to 2.0. loudness and pulse are randomly generated. The multi parallel search and moving to global optimum, this shuffled bat algorithm optimization can be used for any number of bus systems. However parameters are fixed based on the complexity of the problem.

For testing the proposed algorithm, the test data of IEEE-30 bus system are considered [21]. In the test data given load is taken as base load. The 90, 100 and 110% of the base load are taken for optimal placement and sizing of FACTS device. Table 5 shows the voltage profiles with base load and 90,100 and 110% of varying load conditions. Figures 6, 7 and 8 are the voltage profiles of base load, 90%, 100%and 110% of the base load conditions. Table 5 shows voltage profiles with base load and 90,100 and 110% of varying load conditions. From Table 5 it is clearly observed that the voltage profiles are not much affected by the insertion of the series FACTS device. Voltage profiles for all load variations followed by the voltage profile of base loading. Figure 6, Figure 7 and Figure 8 shows the voltage profile of TCSC inserted transmission line.

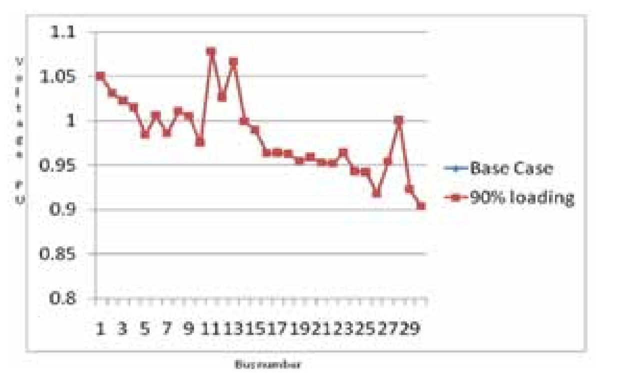

FIG. 6 VOLTAGE PROFILE WITH 90% OF BASE LOAD

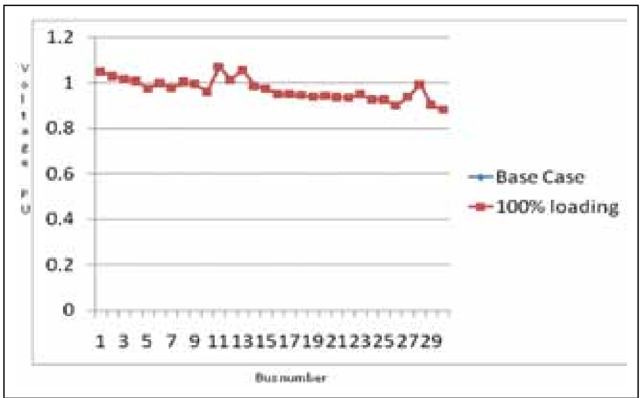

FIG. 7 VOLTAGE PROFILE WITH 100% OF BASE LOAD

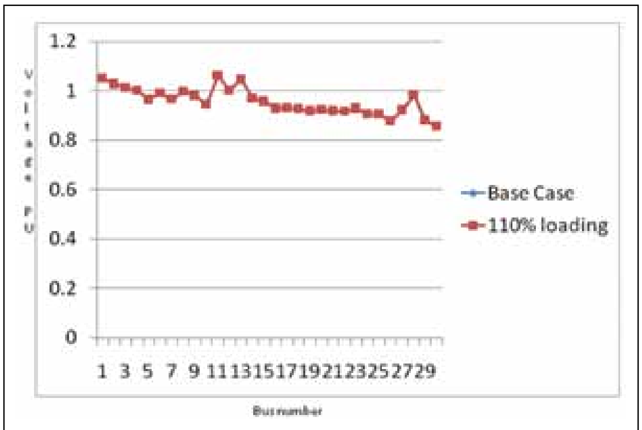

FIG. 8 VOLTAGE PROFILE WITH 110% OF BASE LOAD

TABLE 5

SVC VOLTAGE PROFILES WITH DIFFERENT LOAD VARIATION

S. No	Base Case	90% loading	Base Case	100% loading	Base Case	110% loading
1	1.05	1.05	1.05	1.05	1.05	1.05
2	1.0313	1.0313	1.0299	1.0299	1.0282	1.0282
3	1.0227	1.0227	1.0176	1.0176	1.0117	1.0118
4	1.0148	1.0148	1.0083	1.0083	1.0008	1.0009
5	0.9842	0.9842	0.9755	0.9755	0.9651	0.9651
6	1.0061	1.0061	0.999	0.999	0.9907	0.9906
7	0.9857	0.9857	0.977	0.977	0.9667	0.9666
8	1.0106	1.0106	1.0048	1.0047	0.9977	0.9977
9	1.0056	1.0056	0.9953	0.9953	0.9831	0.9827
10	0.9754	0.9754	0.9617	0.9616	0.9457	0.9452
11	1.0778	1.0778	1.0703	1.0703	1.0612	1.061
12	1.026	1.026	1.0147	1.0146	1.0012	1.0017
13	1.0667	1.0667	1.0572	1.0572	1.0459	1.0462
14	0.9992	0.9992	0.9853	0.9853	0.9691	0.9695
15	0.9892	0.9891	0.9746	0.9746	0.9579	0.9581
16	0.9637	0.9637	0.9485	0.9485	0.9312	0.9289
17	0.964	0.964	0.9493	0.9493	0.9323	0.9312
18	0.9629	0.9629	0.9464	0.9463	0.9274	0.9274
19	0.9548	0.9548	0.9378	0.9378	0.9185	0.9182
20	0.9587	0.9587	0.9424	0.9424	0.9238	0.9234
21	0.9528	0.9528	0.9372	0.9371	0.9191	0.9186
22	0.9521	0.9521	0.9363	0.9363	0.9182	0.9177
23	0.9642	0.9642	0.9481	0.9481	0.9297	0.9297
24	0.943	0.943	0.9259	0.9259	0.9065	0.9062
25	0.9422	0.9421	0.9259	0.9259	0.9072	0.9071
26	0.9178	0.9178	0.8996	0.8996	0.8789	0.8787
27	0.9539	0.9539	0.9391	0.9391	0.922	0.9219
28	1.0005	1.0005	0.9926	0.9926	0.9834	0.9833
29	0.9228	0.9227	0.9039	0.9039	0.8825	0.8824
30	0.9036	0.9036	0.882	0.882	0.8576	0.8575

Table 6 shows the Power flows in various lines of the test system chosen for analysis. From Table 6 it is clearly shows the difference in power flows for different loading is minimum. Figures 9, 10 and 11 are the power flows in different lines with variations in loading. From figures 9, 10, 11 it is clearly observed that as the percentage of loading is increased the power flows are also increased.

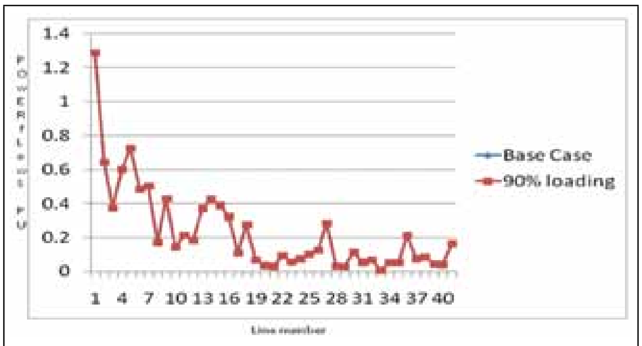

FIG.9 POWER FLOW THROUGH LINES WITH 90% OF BASE LOAD

Table 7 shows the optimal placement and sizing of TCSC device. With 90% loading inductive compensation is provided by TCSC ,whose size is 0.0146 p.u and located in line 6 which connects bus 2 to bus 6.when load variation is 100% , inductive compensation is provided by TCSC with 0.0760 p.u value and located in line 5 which connects bus 2 to bus 5. When percentage load variation is increased to 110 %, TCSC provides capacitive compensation with -0.1432 p.u value which is connected in line 19 which connects between bus12 to bus 16.

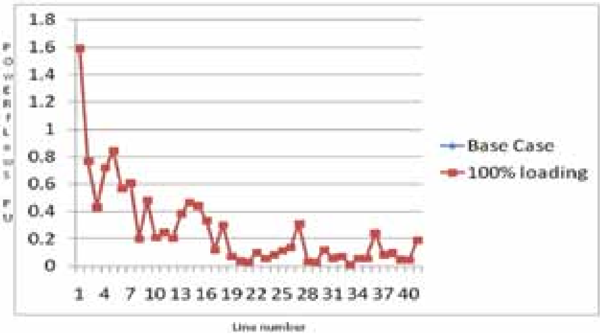

FIG.10 POWER FLOW THROUGH LINES WITH 100% OF BASE LOAD

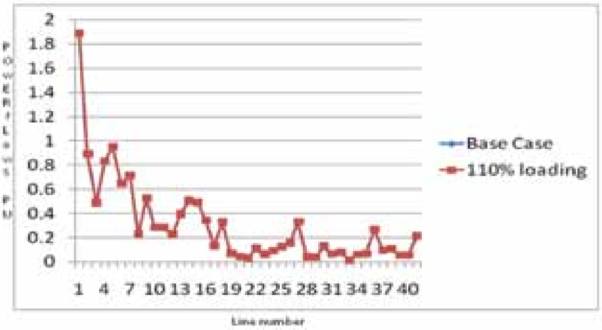

FIG.11 POWER FLOW THROUGH LINES WITH 110% OF BASE LOAD

TABLE 6

POWER FLOWS IN P.U WITH DIFFERENT LOAD VARIATIONS WITH TCSC

S. No	Base Case	90% loading	Base Case	100% loading	Base Case	110% loading
1	1.2868	1.287	1.5842	1.5861	1.889	1.8891
2	0.6427	0.6427	0.7661	0.7663	0.8911	0.8908
3	0.3749	0.3749	0.4308	0.4304	0.4873	0.4869
4	0.6009	0.6008	0.7169	0.7171	0.8339	0.8336
5	0.7255	0.7255	0.8369	0.8396	0.95	0.9502
6	0.485	0.4854	0.5654	0.5651	0.6469	0.6472
7	0.503	0.5029	0.6049	0.6048	0.7097	0.7129
8	0.1725	0.1726	0.1997	0.1992	0.2276	0.2276
9	0.4296	0.4296	0.4781	0.4776	0.5273	0.5271
10	0.1443	0.1448	0.2109	0.2109	0.2825	0.2832
11	0.2142	0.2142	0.2467	0.2467	0.2806	0.2825
12	0.1848	0.1848	0.2051	0.2051	0.226	0.2276
13	0.373	0.3731	0.3817	0.3817	0.3913	0.3921
14	0.4266	0.4266	0.4643	0.4643	0.5027	0.5054
15	0.3898	0.3898	0.4412	0.4412	0.4935	0.4899
16	0.323	0.3231	0.3319	0.3319	0.3422	0.3411
17	0.1112	0.1112	0.1213	0.1213	0.1316	0.1322
18	0.2773	0.2773	0.3005	0.3005	0.3244	0.3269
19	0.0682	0.0682	0.0721	0.0721	0.0763	0.0685
20	0.0356	0.0356	0.0375	0.0375	0.0395	0.04
21	0.0298	0.0297	0.0313	0.0313	0.0332	0.0297
22	0.0937	0.0937	0.1006	0.1006	0.1079	0.1094
23	0.0558	0.0559	0.0585	0.0585	0.0613	0.0625
24	0.075	0.075	0.0833	0.0833	0.0916	0.0896
25	0.1028	0.1028	0.1143	0.1143	0.1258	0.1238
26	0.1266	0.1266	0.1378	0.1378	0.1494	0.1556
27	0.2849	0.2849	0.3085	0.3085	0.3327	0.3313
28	0.0327	0.0327	0.0355	0.0355	0.0383	0.0381
29	0.028	0.028	0.0317	0.0317	0.0356	0.0343
30	0.1136	0.1136	0.1203	0.1203	0.1273	0.1284
31	0.0548	0.0548	0.0596	0.0596	0.0645	0.0627
32	0.0701	0.0701	0.073	0.073	0.0761	0.0769
33	0.0082	0.0082	0.0101	0.0101	0.0123	0.0124
34	0.0519	0.0519	0.0559	0.0559	0.0599	0.0599
35	0.0517	0.0517	0.0582	0.0582	0.0648	0.065
36	0.214	0.214	0.2387	0.2387	0.2637	0.2639
37	0.0762	0.0762	0.0844	0.0844	0.0928	0.0928
38	0.0865	0.0865	0.096	0.096	0.1057	0.1057
39	0.0442	0.0442	0.0491	0.0491	0.054	0.054
40	0.0425	0.0426	0.0467	0.0467	0.0535	0.0536
41	0.1636	0.1636	0.1888	0.1888	0.2141	0.2142

TABLE 7

OPTIMUM LOCATION OF FACTS DEVICE TCSC WITH DIFFERENT LOAD VARIATIONS

S. NO	LOAD VARIATION (%)	SIZING OF TCSC (P.U)	LOCATION OF TCSC (LINE)
1	90	0.0146	6 (BUS 2 TO BUS 6)
2	100	0.0760	5 (BUS 2 TO BUS 5)
3	110	-0.1432	19 (BUS 12 TO BUS 16)

6.0 CONCLUSIONS

This work compares the application of conventional based sensitivity method and shuffled bat algorithm to solve optimal location and sizing of TCSC device by considering branch loading and voltage profile improvement and losses as performance indices. The shuffled BAT algorithm is illustrated to give results for IEEE 30 bus system. Results obtained are compared with conventional sensitivity based method for near optimal values. Results clearly show the shuffled bat algorithm approach is effective in enhancing voltage stability and simultaneously lowering the system losses and increasing the power flows of the transmission network.

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