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Complex Power Flow Sensitivity Index based Optimal Location and Tuning of Thyristor Controlled Series Capacitor using BAT Algorithm to enhance Line based Voltage Stability

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Abstract—Modern electric power utilities are facing many challenges due to increasing complexity in their operation and structure. In the recent times, one of the problems that got wide attention is the power system instabilities due to lack of new transmission facilities. Existing transmission facilities can be better utilized by installing Flexible AC Transmission System (FACTS) devices. The TCSC is the most effective FACTS device used to increase the power transferable capabilities of the transmission line. This paper presents a Sensitivity analysis based Complex Power Flow Sensitivity Index (CPSI) calculated for placing the TCSC at an appropriate location. Once the location to install the TCSC is determined, the optimal tuning of the TCSC is determined through BAT Algorithm. The BAT Algorithm is implemented on multi-criterion objective function to minimize total real power loss, total voltage magnitude deviations, the fuel cost of total real power generation and the branch loading to obtain the Optimal Power Flow. Simulations have been carried out in MATLAB software for the IEEE 57-bus system. The results have been taken for BAT Algorithm based Optimal Power Flow without and with TCSC. The results obtained with BAT Algorithm were compared with Genetic Algorithm (GA).

Keywords- BAT Algorithm, Optimal placement, Sensitivity index, TCSC.

I. INTRODUCTION

Power systems are becoming increasingly more complex due to the interconnection of regional system and deregulation of the overall electricity market (Kundur 1993; Stagg & El- Abid 1968). The existing power network capacities can be increased by installing the Flexible AC Transmission System (FACTS) controllers. The parameters of the transmission line, like line reactance, voltage magnitude, and phase angle can be controlled using the FACTS controllers in a fast and effective way. The credits of the FACTS controllers include improvement of the stability of power system networks, such as voltage stability, line stability, small signal stability, transient stability, enhance power transfer capability and thus enhance system reliability. However, controlling power flows is the main function of the

FACTS controllers (Gyugyi & Hingorani 2000; Acha *et al* 1999).

Although several methods were suggested in literature to protect power system networks against voltage collapse, the placement of FACTS controllers has been established as an effective means. However, due to high cost of the FACTS devices, it is important to optimally place these controllers in the system. The Thyristor Controlled Series Capacitor (TCSC) is one of the most effective Flexible AC Transmission System devices [5, 6]. It regulates the power flow through the transmission line (Lei & Retzmann 2000). Many authors have found the use of TCSC. The TCSC is used to damp power oscillations and to improve the transient stability of power systems (Christa *et al* 2013). The optimal placement of Thyristor Controlled Series Compensators in transmission systems is formulated as a multi-objective optimization problem to minimize the losses (Basu 2008).

This paper presents a Sensitivity analysis based Complex Power Flow Sensitivity Index (CPSI) proposed for placing the TCSC at appropriate location. A new Metaheuristic optimization technique called the BAT algorithm is introduced to find the optimal size of the TCSC device to improve stability. Its performance is compared with the Genetic Algorithm (GA) technique. The real and reactive power generation values and voltage limits for buses are taken as constraints, along with reactance limits of the TCSC, during the optimization. Computer simulations using MATLAB were done for the IEEE 57 bus system. In this paper, a new line-based voltage stability index is proposed to evaluate the stability condition in a power system.

II. PROBLEM FORMULATION

In this paper, a multi objective function is formulated, to find optimal sizing of the TCSC device by minimizing certain objective functions subject to network constraints. The multi-objective problem can be written mathematically as follows,

A. Objective function

For a given system load, we look for the best configuration of TCSC device minimizing the following objective function:

$$\text{Min}(F) = \min (W_1 * FC + W_2 * F_{\text{Ploss}} + W_3 * F_{\text{VD}} + W_4 * F_S) \quad (1)$$

Where W_1, W_2, W_3, W_4 are the weighting factors $W_1 + W_2 + W_3 + W_4 = 1$

$$W_1 = W_2 = W_3 = W_4 = 0.25$$

Reactance of TCSC has been added as a control variable along with real power generation of the generator buses for optimization problem. TCSC limits are given as:

$$X_{\text{TCSC}}^{\min} \leq X_{\text{TCSC}} \leq X_{\text{TCSC}}^{\max} \quad (2)$$

1) Fuel cost:

The objective function considering the minimization of total generation cost can be represented by following quadratic equation

$$FC = \min \left(\sum_{i=1}^{ng} a_i + b_i P_{Gi} + c_i P_{Gi}^2 \right) \quad (3)$$

Where ng = no. of generator buses

a, b, c are the fuel cost coefficients of a generator unit

2) Active Power Loss:

The objective of this function is to minimize real power losses in the transmission lines. It can be expressed as

$$F_{\text{Ploss}} = \min \left(\sum_{k=1}^{ntl} \text{real} (S_{ij}^k + S_{ji}^k) \right) \quad (4)$$

Where ntl = no. Of transmission lines

S_{ij} is the total complex power flow of line $i - j$

3) Voltage Deviation:

To have a good voltage performance, the voltage deviation at each bus must be made as small as possible. The Voltage Deviation (VD) can be expressed as:

$$F_{\text{VD}} = \min(\text{VD}) = \min \left(\sum_{k=1}^{N_{\text{bus}}} : V_k - V_k^{\text{ref}} :^2 \right) \quad (5)$$

V_k is the voltage magnitude at bus k

V_k^{ref} is the reference voltage magnitude at bus k

4) Branch loading:

The objective of minimizing the branch loading in the transmission lines is to enhance the security level of the system. It can be expressed as

$$F_S = \min(S) = \min \left(\sum_{k=1}^{ntl} \left(\frac{S_k}{S_k^{\max}} \right)^2 \right) \quad (6)$$

S_k is the apparent power in line k and $S_k^{\max}$ is the maximum apparent power in line k .

5) Equality constraints:

$$\sum_{i=1}^N P_{Gi} = \sum_{i=1}^N P_{Di} + P_L \quad (7)$$

Where $i=1,2,3,\dots,N_{\text{bus}}$ and N_{bus} = no. of Buses

$$\sum_{i=1}^N Q_{Gi} = \sum_{i=1}^N Q_{Di} + Q_L \quad (8)$$

Where $i=1,2,3,\dots,N_{\text{bus}}$ and N_{bus} = no. of buses

P_L is total active power losses

Q_L is total reactive power losses

6) Inequality constraints:

a) Generator bus Voltage limits:

$$V_{Gi}^{\min} \leq V_{Gi} \leq V_{Gi}^{\max} \quad (9)$$

Where $i=1,2,3,\dots,N_{\text{bus}}$ and N_{bus} = no. of buses

b) Real power generation limit:

$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max} \quad (10)$$

Where $i=1,2,3,\dots,ng$ and ng = no. of generator buses

c) Reactive Power generation limits:

$$Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max} \quad (11)$$

B. Fast Voltage Stability Index (FVSI)

Several techniques were proposed to analyse the static voltage stability condition in a system. Some of them were utilized the voltage stability indices referred either to a bus or to a line as an indicator to voltage collapse. In this paper, a new line-based voltage stability index is proposed to evaluate the line stability condition in a power system. This index is called as Fast Voltage Stability Index (FVSI). The system becomes unstable if FVSI is equal to or greater than unity.

1) FVSI (Fast Voltage Stability Index)

FVSI can be expressed as

$$FVSI_{ij} = \frac{4 Z^2 Q_j}{V_i^2 X} \quad (12)$$

Where Z is the line impedance

X is the line reactance

Q_j is the reactive power at bus j (receiving end bus)

V_i is the voltage magnitude at bus i (sending end bus)

Any line in the system that exhibits FVSI close to unity indicate that the line is may lead to system violation. Therefore, FVSI has to be maintained less than unity in order to maintain a stable system.

III. THYRISTOR CONTROLLED SERIES CAPACITOR

Thyristor controlled series capacitor (TCSC) controller consists of a series capacitor paralleled by a thyristor-controlled reactor in order to provide smooth variable series compensation. The basic Thyristor-controlled series capacitor scheme was proposed in 1986 by Vithaythil along with others. Apart from enhancing system stability, the TCSC also increases the line power transfer capability. The basic module of a TCSC is shown in Fig. 1. It consists of three components: capacitor banks C , bypass inductor L and bidirectional thyristors (Gerbex and Germond 2001; Acha *et al* 2000; Ambriz- Perez *et al* 2006). Thyristor inhibition in the TCSC module enables it to have a smoother control over its reactance in response to system parameter variations.

Figure1. Basic TCSC model

X_C = fixed capacitive impedance

$X_L(\alpha)$ = variable inductive impedance

$$X_{TCSC}(\alpha) = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C} \quad (13)$$

Where

$$X_L(\alpha) = \frac{X_L(\pi)}{\pi - 2\alpha - (\sin 2\alpha)}$$

$$X_{Lmin} \leq X_L(\alpha) \leq X_{Lmax} \quad (14)$$

Where $X_L = \omega L$ and α = delay angle

However, it may be argued that the primary function of the TCSC is to reduce the electrical length of the compensated transmission line. So as to increase power transfers significantly with increased transient stability margins. The TCSC power flow model presented in this section is based on the simple concept of a variable series

reactance, the value of which is adjusted automatically to constraint the power flow across the branch is specified. The amount of reactance is determined efficiently using BAT Algorithm. The changing reactance X_{TCSC} , shown in Figure 2, represents the equivalent reactance of all the series-connected modules making up the TCSC, when operating in either the inductive or the capacitive regions (Abdel & Padhy 2005).

Figure 2. Thyristor-controlled series capacitor equivalent circuit: Inductive and capacitive operative regions

The transfer admittance matrix of the variable series compensator shown in Figure 2 is given by

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} jB_{kk} & jB_{km} \\ jB_{mk} & jB_{mm} \end{bmatrix} \begin{bmatrix} V_k \\ V_m \end{bmatrix} \quad (15)$$

For capacitive operation, we have

$$B_{kk} = B_{mm} = \frac{1}{X_{TCSC}}$$

$$B_{km} = B_{mk} = \frac{1}{X_{TCSC}} \quad (16)$$

For inductive operation the signs are reversed

The active and reactive power equations at bus k are:

$$P_k = [V_k V_m B_{km} \sin(\theta_k - \theta_m)] \quad (17)$$

$$Q_k = -V_k^2 B_{kk} - [V_k V_m B_{km} \cos(\theta_k - \theta_m)] \quad (18)$$

The series reactance regulates the amount of active power flowing from bus k to bus m the change in reactance of TCSC is

$$\Delta X_{TCSC} = X_{TCSC}^i - X_{TCSC}^{(i-1)} \quad (19)$$

The state variable X_{TCSC} of the series controller is updated at the end of each iterative step according to

$$X_{TCSC}^i = X_{TCSC}^{(i-1)} + \left(\frac{\Delta X_{TCSC}}{X_{TCSC}} \right)^i X_{TCSC}^{(i-1)} \quad (20)$$

IV. COMPLEX POWER FLOW SENSITIVITY INDEX FOR OPTIMAL PLACEMENT OF TCSC

A method based on the sensitivity of the sum of variations of complex power flow in all lines with respect to the change of reactance of a line is proposed. The TCSC has been modelled as a variable series capacitive reactance X_{TCSC} , resulting in a decrease of the total line reactance. The index is computed using Newton Raphson power flow. $CPSI_j$ at a line j is given as:

$$CPSI_j = \sum_{n=1}^{ntl} \frac{\Delta S_n}{\Delta X_j} \quad (21)$$

Where $n=1, 2, 3, \dots, ntl$ and ntl = no. of transmission lines.

ΔS_n is change in complex power flow in line n

ΔX_j is reactance of the line j

This index is calculated for all the lines. The minimum and maximum values of $CPSI$ are obtained. Normalized complex power flow sensitivity index is defined as:

$$CPSI_{nj} = \frac{CPSI_j - CPSI_{min}}{CPSI_{max} - CPSI_{min}} \quad (22)$$

where $CPSI_{nj}$ is the normalized complex power flow sensitivity index at line j

Highest normalized complex power flow sensitivity index is the best location for placement of TCSC. From the Table 4.1 it is observed that highest positive value of $CPSI_n(j)$ is 1 for line no 76 and TCSC is placed in line number 76. Complex power flow sensitivity Indexes for all lines in the IEEE 57 bus system.

TABLE I.

COMPLEX POWER FLOW SENSITIVITY INDEXES FOR ALL LINES IN THE IEEE 57 BUS SYSTEM.

S.No	Line No	$CPSI_n(j)$	S.No	Line No	$CPSI_n(j)$
1	76	1	41	80	0.8837
2	36	0.9987	42	32	0.88
3	73	0.9986	43	17	0.8666
4	35	0.9982	44	58	0.863

5	46	0.9951	45	6	0.8616
6	31	0.9915	46	50	0.8593
7	44	0.991	47	68	0.8551
8	54	0.99	48	39	0.8506
9	29	0.9889	49	15	0.8426
10	19	0.9836	50	10	0.8324
11	74	0.9833	51	14	0.832
12	43	0.9804	52	2	0.8316
13	30	0.9759	53	26	0.8217
14	20	0.9755	54	47	0.8142
15	56	0.9733	55	59	0.8055
16	75	0.9679	56	24	0.8032
17	55	0.9675	57	65	0.7947
18	11	0.9582	58	22	0.794
19	77	0.9523	59	60	0.7883
20	34	0.9514	60	41	0.7746
21	38	0.951	61	21	0.7716
22	69	0.945	62	25	0.7583
23	70	0.9434	63	40	0.7499
24	64	0.9412	64	57	0.7478
25	42	0.9351	65	28	0.7311
26	16	0.9348	66	48	0.7248
27	67	0.9291	67	18	0.7194
28	66	0.9283	68	8	0.7106
29	27	0.9244	69	79	0.6948
30	78	0.9241	70	37	0.6865
31	7	0.9219	71	52	0.6816
32	9	0.9195	72	13	0.6612
33	12	0.9141	73	51	0.6058
34	71	0.9101	74	3	0.5956
35	5	0.9079	75	49	0.5916
36	4	0.8954	76	45	0.5844
37	62	0.8922	77	53	0.4902
38	63	0.8914	78	1	0.4612
39	23	0.8909	79	61	0.353
40	72	0.8868	80	33	0

V. OPTIMAL SIZING OF TCSC USING THE BAT ALGORITHM

The BAT algorithm has been used to find the optimum sizing of TCSC. BAT Algorithm is a nature inspired metaheuristic algorithm which is developed by Xin-She Yang in 2010. Metaheuristic algorithms use certain trade-off of randomization and local search. Randomization supplies a good way to move away from local search to the search on the global scale (Yang 2008). This algorithm is based on the echolocation behaviour of micro bats. Micro bats use a type of sonar to detect food and prey, avoid obstacles and locate their roosting chink in the dark. These bats emit a very loud sound pulse and listen for the echo that bounces back from surrounding objects. BAT algorithm is developed by considering some of the characteristics of micro bats following the rules. (Yang 2011)

A. Population

The initial population i.e., number of virtual bats for BAT (n) is generated randomly. The number of bats may be anywhere between 0 and 20. After finding the initial fitness of the population for the given function, the values are modified based on their movement, intensity and pulse rate.

B. Movement of Virtual Bats

The rules for modifying the positions x_{ii} and velocities v_{ii} of the virtual bats are given as (23)

$$\begin{aligned} f_{ii} &= f_{min} + (f_{max} - f_{min})\beta \\ v_{ii}^t &= v_{ii}^{t-1} + (x_{ii}^t - x_0) f_{ii} \\ x_{ii}^t &= x_{ii}^{t-1} + v_{ii}^t \end{aligned} \quad (23)$$

Where, $\beta \in [0, 1]$ is a random vector drawn from an identical distribution. Here x_0 is the current global best location which is located after comparing all the solutions with all the n bats. For the local search part, once a solution is selected in current best solutions, a new solution for each bat is create locally using random walk given by equation (24)

$$x_{new} = x_{old} + \epsilon A^t \quad (24)$$

where $\epsilon \in [-1, 1]$ is a random number, while $A_t = A_{it}$ is the average loudness of all the bats at this time step. Based on these approximations and admiration, the basic steps of the BAT Algorithm can be iterate as the pseudo code (Yang 2010).

C. Loudness and Pulse Emission

The loudness A_{ii} and the rate of pulse emission r_{ii} are updated accordingly as the iterations proceed. The loudness decreases and rate of pulse emission increases as the bat closes on its food i.e., the equations for convergence can be taken as below.

$$A_{ii}^{t+1} = \alpha A_{ii}^t$$

$R_{ii}^{t+1} = r_{ii}^0 [1 - \exp(-\gamma t)]$, Where α and γ are constants.

For any $0 < \alpha < 1$ and $\gamma > 0$, we have

$$A_{ii}^t \rightarrow 0, r_{ii}^t \rightarrow r_{ii}^0 \text{ as } t \rightarrow \infty$$

The initial loudness A_0 can typically be (1, 2), while the initial emission rate r_{ii0} can be (0, 1).

VI. RESULTS AND DISCUSSION

In order to find the use of the BAT Algorithm for Optimal Power Flow with the TCSC, the IEEE57 bus system is taken. An OPF program using BAT algorithm is implemented in MATLAB software without and with the TCSC. The results are presented and analysed. The input parameters of BAT Algorithm for the test system are given in the Table II. The generator characteristics of the IEEE 57 bus is given in Table III.

TABLE II

INPUT PARAMETERS OF BAT ALGORITHM

S.No	Parameters	Quantity
1	Population size	20
2	Number of generations	50
3	Loudness	0.5
4	Pulse rate	0.5

TABLE III

GENERATOR CHARACTERISTICS OF IEEE 57 BUS SYSTEM

Generator bus no	a (\$/MW ² /hr)	b (\$/MW/hr)	c (\$/hr)	P_G^{min} (MW)	P_G^{max} (MW)
1	0.0775	20	0	0	575
2	0.01	40	0	0	100
3	0.25	20	0	0	140
6	0.1	40	0	0	100
8	0.02222	20	0	0	550
9	0.01	40	0	0	200
12	0.32258	20	0	0	410

In IEEE 57 bus system, bus 1 is considered as slack bus and buses 2,3,6,8,9,12 are considered as generator buses. It consists of 50 load buses and 80 transmission lines. Considering all the parameters of the system, generation reallocation is carried out with a multi objective function which is formed by considering the cost of the real power generation, active power losses, voltage deviation and branch loading. Results are presented in Table IV to VI.

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As metaheuristic algorithms are based on probabilistic approach, the solutions obtained are not unique. The BAT algorithm based Optimal Power Flows is run 50 times and its best, worst and average values are determined. The best value is considered for Optimal Power Flow solution.

TABLE IV

COMPARISON OF OBJECTIVE FUNCTION PARAMETERS OF MULTI OBJECTIVE OPTIMIZATION USING BAT-OPF CONSIDERING WITHOUT IN IEEE 57 BUS SYSTEM

Variables	BAT-OPF without TCSC		
	(Best)	(Average)	(Worst)
PG1(MW)	167.4362	175.9858	184.5353
PG2(MW)	85.3003	90.71105	96.1218
PG3(MW)	140.0000	140	140.0000
PG6(MW)	41.6669	48.78105	55.8952
PG8(MW)	550.0000	550	550.0000
PG9(MW)	200.0000	196.0988	192.1975
PG12(MW)	60.2578	47.1392	34.0206
Total real power generation	1244.6612	1248.716	1252.7704
Total reactive power generation	350.7705	375.684	400.5975
Total real power generation cost	47144.4847	47296.22	47447.9501
Active power Loss	48.8612	52.9158	56.9704
Voltage deviation	5.7725	6.45445	7.1364
Branch loading	13.8017	14.25145	14.7012
FVSI	7.8545	8.47325	9.0920
Reactance of TCSC	---	----	----
Objective function value	11803.2300	11842.46	11881.6895

TABLE V

COMPARISON OF OBJECTIVE FUNCTION PARAMETERS OF MULTI OBJECTIVE OPTIMIZATION USING BAT-OPF CONSIDERING WITH TCSC IN IEEE 57 BUS SYSTEM

Variables	BAT OPF with TCSC connected in Line no 76		
	(Best)	(Average)	(Worst)
PG1(MW)	191.4760	187.4594	183.4427
PG2(MW)	45.5955	67.12505	88.6546
PG3(MW)	58.8534	55.5613	52.2692
PG6(MW)	98.0000	84.95275	71.9055
PG8(MW)	550.0000	550	550.0000
PG9(MW)	200.0000	200	200.0000
PG12(MW)	98.5849	98.4601	98.3353
Total real power generation	1242.5099	1243.559	1244.6073
Total reactive power generation	338.4303	351.7879	365.1454
Total real power generation cost	46789.0644	46809.94	46830.8147
Active power Loss	46.7099	47.7586	48.8073
Voltage deviation	4.9258	5.36205	5.7983
Branch loading	13.8640	14.0726	14.2812
FVSI	7.7512	8.14505	8.5389
Reactance of TCSC	0.3278	0.3348	0.3418
Objective function value	11713.6410	11719.28	11724.9254

The results from Table VI, V, VI show that , for minimization of the multi objective function, the generation cost of the best solution is 46789.0644 \$/hr with 46.7099 MW line loss, 4.9258 voltage deviation and 13.8640 branch loading. The results in Table VI indicate the values of the different parameters of the different objective function using BAT considering with TCSC. From this table it can be observed that all the objective function parameters are optimized simultaneously.

TABLE VI

COMPARISON OF OBJECTIVE FUNCTION PARAMETERS USING GA, BAT, FA-OPF CONSIDERING WITHOUT AND WITH TCSC IN IEEE 57 BUS SYSTEM

Variables	GA-OPF without TCSC	BAT-OPF without TCSC	GA OPF with TCSC at line no 76	BAT OPF with TCSC at line no 76
PG1(MW)	242.828	167.43	241.8295	191.4760
PG2(MW)	100.000	85.300	100.0000	45.5955
PG3(MW)	71.9212	140.00	69.8740	58.8534
PG6(MW)	100.000	41.666	100.0000	98.0000
PG8(MW)	550.000	550.00	550.0000	550.0000
PG9(MW)	110.631	200.00	110.6312	200.0000
PG12(MW)	69.8740	60.257	71.9212	98.5849
Total real power generation	1245.25	1244.6	1244.255	1242.5099
Total reactive power generation	354.480	350.77	321.1757	338.4303
Total real power generation cost	47701.1	47144.4	47689.09	46789.0
Active power Loss	49.4550	48.861	49.2455	46.7099
Voltage deviation	5.9295	5.7725	4.9056	4.9258
Branch loading	13.8480	13.801	14.1600	13.8640
FVSI	7.9431	7.8545	7.5205	7.7512
Reactance of TCSC	----	---	0.4201	0.3278
Objective function value	11942.5	11803.2	11939.35	11713.6

From Figure 3 it is observed that the active power losses of the system are reduced by an appreciable amount with the placement of TCSC in BAT algorithm.

Figure3. comparisons of Real Power Losses

Table VII indicates the TCSC parameters for different specified real power flows through the line. From this Table it has been observed that by increasing power flow through the line, TCSC parameter value has been decreased.

TABLE VII

REACTANCE OF TCSC FOR DIFFERENT METHODS WITH SPECIFIED POWER FLOW IN TCSC (TCSC PLACED IN LINE NO 76)

S.No	Real power flow through TCSC installed line	GA-OPF with TCSC X_{tcsc}	BAT-OPF with TCSC X_{tcsc}
1	P=1MW	4.6656	4.6474
2	P=1.5MW	2.5481	2.3672
3	P=2MW	1.4457	1.2928
4	P=2.5MW	0.7341	0.6366
5	P=3MW	0.4201	0.3278
6	P=3.1MW	0.1383	0.0850

TABLE VIII

BEST, WORST AND AVERAGE OF OBJECTIVE FUNCTION FOR IEEE57-BUS SYSTEM USING BAT ALGORITHM

Objective function value	L=0.2 PR=0.2	L=0.5 PR=0.2	L=0.2 PR=0.5	L=0.5 PR=0.5
Average	11845.98	11854.98	11823.665	11814.434
Worst	11888.79	11870.84	11841.804	11825.123
Best	11836.98	11830.47	11811.232	11803.230

L= Loudness PR=Pulse Rate

Table VIII represents the objective function values with varying BAT algorithm parameters and it is observed that taking Loudness and Pulse rate equal to 0.5 in BAT algorithm gave better results compared to other values, so in this analysis BAT parameters are considered as 0.5.

Figure .4, Figure .5 shows the convergence of the objective function using BAT algorithm and Genetic algorithm considering without and with TCSC respectively. From these figures it is observed that Genetic Algorithm takes more number of generations to converge when compared to BAT. From these figures it is observed that BAT Algorithm gives better result and takes less number of generations to converge. Same thing is holds good for without TCSC.

Figure 4. Convergence of the Objective Function with BAT and GA

Figure 5. Convergence of the objective function with BAT and GA without TCSC

Figure 6 represents the comparison of voltage profiles with and without TCSC using BAT Algorithm. It is observed that by installing TCSC optimally in power system improves the voltage profile of the buses. Figure 7 represents the Fast Voltage Stability Index for lines with and without TCSC using BAT Algorithm. From these figures it is observed that by incorporating the TCSC in the system voltage stability has been improved.

Figure 6. Comparison of the Voltage Magnitudes with and without TCSC

REFERENCES

Figure 7. Comparison of FVSI with and without TCSC using BAT Algorithm

VII. CONCLUSION

In this paper, Sensitivity Analysis based Complex Power Flow Sensitivity Index (CPSI) has been implemented for optimal location of the TCSC. After placing the TCSC in the best location, a new swarm based BAT Algorithm has been presented to solve the optimal sizing of TCSC. The effectiveness of BAT Algorithm was presented. The results show that incorporating the TCSC in the IEEE 57 bus system can reduce the total active power losses, improve the voltage profile of the system and enhance the line based voltage stability. For finding the best size of a TCSC, BAT Algorithm based optimization technique, with the objective of reducing total generation cost, voltage deviation, active power losses and branch loading was implemented. The comparative study of the BAT Algorithm based Optimal Power Flow with GA based Optimal Power Flow in solving the optimal tuning problem, indicates the effectiveness of the proposed approach. The obtained results show that the TCSC is the most effective series compensation device that can significantly increase the line based voltage stability of the power system.

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