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Parameter Optimisation of FACTS using Cuckoo Search Algorithm for ATC Enhancement in Restructured Power Systems

Bavithra K.*,[1], Charles Raja S.[+], Anadhakumar K.* and Latha R.[^]

Abstract *– In electrical industry, deregulation intended at creating economical markets to do business with electricity. Many utilities provide transaction services for wholesale customers, they must know about the post information on ATC of their transmission networks. Such information will help power marketers, sellers and buyers in reserving transmission services. ATC must be rapidly updated for new capacity reservations. Various mathematical models have been developed by the researchers to determine the ATC. ATC is an impending question in the conceptualization of deregulation in addition to congestion management and pricing. This research work follows a line of investigation of calculating ATC using AC- power transfer distribution factors (AC-PTDF) and its enhancement using flexible AC transmission system (FACTS) devices like static compensator (STATCOM) and unified power flow controller (UPFC). This solution eliminates extravagance in erecting new transmission system. FACTs devices whose settings are optimized using cuckoo search algorithm (CSA) are placed by accounting sensitivity of lines to provide reactive power that recuperates the ATC of the desired line. Undoubtedly, it is very important and imperative to carry out studies on exploitation of FACTS technology to enhance the ATC. The Bilateral and multi-lateral transactions are randomly chosen and tested in IEEE 30 and sample 6 bus system.*

Keywords *– AC- power transfer distribution factor, bilateral and multi-lateral transactions, open access, slope of linear sensitivity factors.*

1. INTRODUCTION

Since many utilities provide transaction services for wholesale customers, they must know about the post information on ATC of their transmission networks. ATC must be rapidly updated for new capacity reservations, schedules or transactions, various mathematical models have been developed by the researchers to determine the ATC of the transmission system.AC-PTDF technique is adopted to determine ATC by Manikandan *et al.* [6] FACTS devices are employed to enhance them is acknowledged by Ashwani *et al.* [1]. The PSO algorithm is used to obtain the optimal settings of FACTS devices for enhancement of ATC is approached by Bavithra *et al.* [4] and same by modified PSO is dealt by Jeslin *et al.* [5]. CSA is proposed and engaged to solve electrical issues by Basu *et al.* [3], Ramin *et al.* [7]. The security issues are also accounted by abdelaziz *et al.* [2]. This paper aims at determining ATC using AC-PTDF technique and enhanced them using STATCOM, UPFC whose optimal settings are obtained using CSA thus evading significant concern of deregulation.

2. METHODOLOGY

2.1 ATC computation by ACPTDF Methodology

The PTDF measures the sensitivity of line real power flows to a real power transfer. PTDF of line i-j for transaction m-n is given as:

$$PTDF_{ij,mn} = \Delta p_{ij} / p_{mn} \tag{1}$$

Where, P_{mn} is the transacted power flow between seller bus m and buyer bus n.

$$\Delta P_{ij} = \left[\frac{\partial P_{ij}}{\partial V_i}\right]\Delta V_i + \left[\frac{\partial P_{ij}}{\partial V_i}\right]\Delta V_j + \left[\frac{\partial P_{ij}}{\partial \delta_i}\right]\Delta \delta_i + \left[\frac{\partial P_{ij}}{\partial \delta_i}\right]\Delta \delta_j \tag{2}$$

Equation 2 may be written as:

$$\Delta P_{ij} = \left[\frac{\partial P_{ij}}{\partial \delta_2} \cdots \frac{\partial P_{ij}}{\partial \delta_n}\frac{\partial P_{ij}}{\partial V_2} \cdots \frac{\partial P_{ij}}{\partial V_n}\right] * \begin{bmatrix} \partial \delta_2 \\ . \\ . \\ \partial \delta_n \\ \partial V_2 \\ . \\ . \\ \partial V_n \end{bmatrix} \tag{3}$$

*Department of Electrical and Electronics Engineering, PSG Institute of Technology and Applied Research, Coimbatore – 641 062

+Department of Electrical and Electronics Engineering, Thiagarajar College of Engineering, Madurai – 625 015

^Department of Electrical and Electronics Engineering, PSG College of Technology, Coimbatore-641 004

1Corresponding author;
Tel: +91 9976124554.
Email: lavitrabavishya@gmail.com.

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$$\Delta P_{ij} = \left[\frac{\partial P_{ij}}{\partial \delta_2} \cdots \frac{\partial P_{ij}}{\partial \delta_n} \frac{\partial P_{ij}}{\partial V_2} \cdots \frac{\partial P_{ij}}{\partial V_n} \right] * \begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ . \\ . \\ +Pt \\ 0 \\ . \\ . \\ -Pt \\ 0 \end{bmatrix} \quad (4)$$

In NR power flow, the voltage and its angle is related with reactive and real power transfer between the buses, hence the Facts devices can be modeled by changing existing jacobian matrix. The power transfer of line i-j in the system is given as$T_{ij,mn}$ due to contract m-n is,

$$T_{ij,mn} = \begin{cases} \dfrac{\left(P_{ij}^{max} - P_{ij}^{0}\right)}{PTDF_{ij,mn}} \; ; & PTDF_{ij,mn} > 0 \\ \alpha(infinite) \; ; & PTDF_{ij,mn} = 0 \\ \dfrac{(-P_{ij}^{max} - P_{ij}^{0})}{PTDF_{ij,mn}} \; ; & PTDF_{ij,mn} < 0 \end{cases} \quad (5)$$

Where;
P_{ij}^{max} is the real power of a line i-j
P_0^{ij} is the base case power in line i-j
$PTDF_{ij,mn}$ is the PTDF for the line i-j when a transaction is taking place between bus m and n

$$ATC_{mn} = \min\left\{ T_{ij,mn} \right\}, \; ij \in N_L \quad (6)$$

Where;
N_L is the total number of lines in the system.

2.2 Power Flow Modelling of FACTS Devices

For the power flow analysis, the FACTS devices like STATCOM, SSSC and UPFC are embodied by a synchronous voltage source with voltage magnitude (Vsh/Vse), and voltage angle (deltash /deltase), with its internal impedance (Zsh/Zse).

2.2.1 Static compensator (STATCOM)

STATCOM a shunt connected FACTS control device is controlled by three shunt parameters like voltage, angle and impedance. The model is shown in Figure 1. The real and reactive power flows equations of STATCOM are,

$$P_i^{STATCOM} = V_i^2 G_{sh} + V_i V_{sh} [G_{sh} cos(\delta_i - \delta_{sh}) + B_{sh} sin(\delta_i - \delta_{sh})] \quad (7)$$

$$Q_i^{STATCOM} = -V_i^2 B_{sh} + V_i V_{sh} [G_{sh} sin \delta_i - \delta_{sh}) - B_{sh} cos(\delta_i - \delta_{sh})] \quad (8)$$

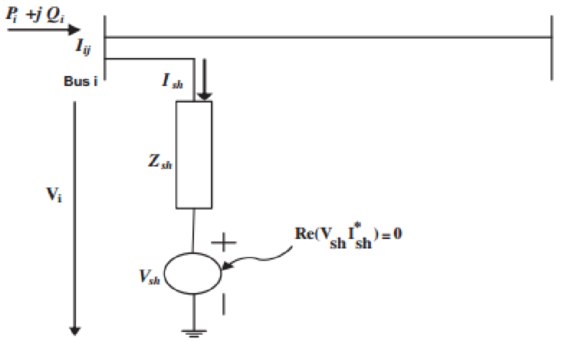

Fig. 1. Equivalent circuit of static synchronous compensator.

By assuming the real power generation as zero, the reactive power injection at Bus i can be calculated by modeling only the sub-jacobian matrixes J3 and J4 diagonal elements as,

$$\begin{bmatrix} J_1 & J_2 \\ J_3^{STATCOM} & J_4^{STATCOM} \end{bmatrix} \quad (9)$$

Where,

$$J_{3,statcom}(i,i) = J_3(i,i) + V_i V_{sh} [G_{sh} cos(\delta_i - \delta_{sh}) + B_{sh} sin(\delta_i - \delta_{sh})] \quad (10)$$

$$J_{4,statcom}(i,i) = J_4(i,i) + V_{sh} [G_{sh} sin(\delta_i - \delta_{sh}) - B_{sh} cos(\delta_i - \delta_{sh})] \quad (11)$$

2.2.2 Unified power flow controller (UPFC)

The UPFC model is shown in Figure 2. The real and reactive power flow equations for UPFC are:

$$P_{ij}^{upfc} = V_i^2 (G_{ii} + G_{sh}) + V_i V_j [G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})] + V_i V_{se} [G_{ij} \cos(\delta_i - \delta_{se}) + B_{ij} \sin(\delta_j - \delta_{se})] + V_i V_{sh} [G_{ij} \cos(\delta_i - \delta_{sh}) + B_{sh} \sin(\delta_i - \delta_{sh})] \quad (12)$$

$$Q_{ij}^{upfc} = -V_i^2 (B_{ii} + B_{sh}) + V_i V_j [G_{ij} \sin(\delta_{ij}) - B_{ij} \cos(\delta_{ij})] + V_i V_{se} [G_{ij} \cos(\delta_i - \delta_{se}) - B_{ij} \cos(\delta_i - \delta_{se})] + V_i V_{sh} [G_{ij} \sin(\delta_i - \delta_{sh}) + B_{sh} \cos(\delta_i - \delta_{sh})] \quad (13)$$

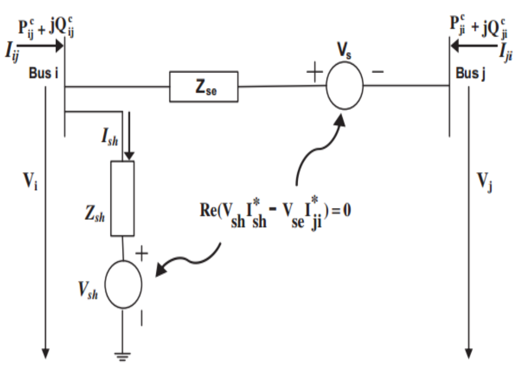

Fig. 2. Equivalent circuit of unified power flow controller.

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The change in diagonal elements of J1, J2, J3, and J4 after inserting UPFC as,

$$\begin{bmatrix} J1^{UPFC} & J2^{UPFC} \\ J3^{UPFC} & J4^{UPFC} \end{bmatrix} \tag{14}$$

$$J_{1,upfc}(i,i) = J_1(i,i) + V_iV_{se}[-\sin(\delta_i - \delta_{se}) + B_{ij}\cos(\delta_j - \delta_{se})] + V_iV_{sh}[-(G_{ij} + G_{sh})\sin(\delta_i - \delta_{sh}) + B_{ij}\cos(\delta_i - \delta_{sh})] \tag{15}$$

$$J_{2,upfc}(i,i) = J_2(i,i) + V_{se}[G_{ij}\cos(\delta_i - \delta_{se}) + B_{ij}\cos(\delta_i - \delta_{se})] + V_{sh}[G_{sh}\cos(\delta_i - \delta_{sh}) + B_{ij}\sin(\delta_i - \delta_{sh})] \tag{16}$$

$$J_{3,upfc}(j,j) = J_1(j,j) + V_jV_{se}[G_{ij}\cos(\delta_j - \delta_{se}) + B_{ij}\sin(\delta_j - \delta_{se})] \tag{17}$$

$$J_{4,upfc}(j,j) = J_2(j,j) + V_{se}[G_{ij}\sin(\delta_j - \delta_{se}) - B_{ij}\cos(\delta_j - \delta_{se})] \tag{18}$$

2.3 Calculation of ATC after incorporation of FACTS Devices

After incorporation of all modification in Jacobian matrix, the PTDF can be obtained as:

$$PTDF^{ij}_{mn,FACTS} = \left[\frac{\partial P_{ij}^{FACTS}}{\partial \delta_2} \cdots \frac{\partial P_{ij}^{FACTS}}{\partial \delta_n} \frac{\partial P_{ij}^{FACTS}}{\partial V_2} \cdots \frac{\partial P_{ij}^{FACTS}}{\partial V_n}\right] * \begin{bmatrix} J1_{FACTS} & J2_{FACTS} \\ J3_{FACTS} & J4_{FACTS} \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ . \\ . \\ +1 \\ 0 \\ . \\ . \\ -1 \end{bmatrix} \tag{19}$$

ATC enhancement by FACTS devices can be found as:

$$T_{ij,mn}^{FACTS} = \begin{bmatrix} \dfrac{(P_{ij}^{max} - P_{ij}^{0})}{PTDF_{ij,mn}^{FACTS}}; PTDF_{ij,mn}^{FACTS} > 0 \\ inf; \quad PTDF_{ij,mn} = 0 \\ \dfrac{(P_{ij}^{max} - P_{ij}^{0})}{PTDF_{ij,mn}^{FACTS}}; PTDF_{ij,mn}^{FACTS} < 0 \end{bmatrix} \tag{20}$$

$$ATC_{mn}^{FACTS} = min\{T_{ij,mn}^{FACTS}, \ ij \in N_L\} \tag{21}$$

$T_{ij,mn}^{Facts}$ is power transfer of line i-j in the system due to transaction m-n after incorporating Facts devices.

2.4 Objective Function

The objective function of the given problem is:

$$MAX\{ATC_{mn}^{FACTS}\} \tag{22}$$

Subject to:

FACTS constraints:

STATCOM: 0.9<Vsh<1.1 (23)

UPFC: 0.9<Vsh<1.05

Power flow constraints:

Voltage constraint of PQ bus

$$V_i^{min} \le V_i \le V_i^{max}$$

Where V_i^{min} and V_i^{max} are minimum and maximum voltage limit at bus I, respectively.

Thermal limit on lines, $P_{ij} < P_{ij}^{max}$

Real power generation constraint,

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max}$$

It is preferable for the maximization of ATC with appropriate settings of FACTS devices. Conventional approach proves to be difficult for multimodal and multivariable problem like parameter settings between their respective min-max limits. On the other hand, EAs are population-based optimization process and converge to the global optimum solution with probability one by a finite number of evolution steps performed on a finite set of possible solutions. Hence, CSA is preferred. Though, ATC are local phenomenon but its enhancement is based on the FACTS parameter settings, *i.e.*, the control parameter variance can align the results on a different domain, which has to be tuned finely to attain best results. For shunt or series or shunt and series impedances are found between their specific ranges using CSA. The ranges for voltage deviation are mentioned in Equation 23.

2.5 Overview of CSA

Cuckoo search is based on three idealized rules [7]:

(1) Each cuckoo lays one egg (a design solution) at a time, and dumps its egg in a randomly chosen nest among the fixed number of available host nests.

(2) The best nests with high quality of egg (better solution) will be carried over to the next generation.

(3) The number of available hosts nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability of pa ͺ [0,1]. In this case, it can simply either throw the egg away or abandon the nest and find a new location to build a completely new one.

2.5.1. Initialization of new population

To create a new population of variables like shunt voltage, angle and impedance the random generation is adopted

$$Var_{ij} = Var_j^{min} + rand * (Var_j^{max} - Var_j^{min}) \tag{24}$$

It is generated according to the size of host nest specified.

2.5.2 Generation of new solution via levy flight

$$X^{new}{}_i = Xbest_i + \alpha * rand_2 * \Delta X_i^{new} \tag{25}$$

Where α > 0 is the updated step size and rand2 is a normally distributed stochastic number. X_i^{new} is calculated as follows,

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$$X^{new}{}_i = v * \sigma_x(\beta) / \sigma_y(\beta) * (Xbest_i - Gbest_i) \quad (26)$$

$$v = rand_x / |rand_y|^{1/\beta} \quad (27)$$

$$\sigma_x(\beta) = [\gamma(1+\beta) * \sin(\frac{\Pi\beta}{2}) / \gamma * (\frac{1+\beta}{2}) * \beta * 2(\frac{\beta-1}{2})]^{1/\beta} \quad (28)$$

$$\sigma_y(\beta) = 1 \quad (29)$$

Where, β is the distribution factor 0.3< β <1.99 and ϒ (.) is the gamma distribution function.

2.5.3 Alien egg discovery and randomization

The action of discovery of an alien egg in a nest of a host bird with the probability of P_a also creates a new solution for the problem similar to the Levy flights. The new solution due to this action can be found out in the following way.

$$\Delta X_i^{dis} = rand_3 + [randP_1(Xbest_i) - randP_2(Xbest_i)] \quad (30)$$

3. RESULTS AND DISCUSSION

This work has been carried out on sample 6 bus system and 30 bus system. The sample 6 bus system has 2 generator buses, three load buses along with eleven transmission lines. IEEE 30 bus system has 6 generators, 21 loads along with 41 transmission lines. The total system demand of 30 bus system is 283.4 MW and 210.0 MW for 6 bus system. The first bus is considered as slack bus in both cases. For 6 bus system, the transactions considered are, 1-6, 3-4, 1-5, 2,3 - 4,5 as BT1, BT2, BT3, MT1 respectively. For 30 bus system, the transactions considered are, 1-12, 5-23, and 2-12 as BT1, BT2, and BT3 respectively. The first bus is seller bus and second bus is buyer bus and a multi-lateral transaction MT (2, 3 - 4, 5) first two are seller bus and last two are buyer bus.

The coefficient of linear relationship between the amount of transaction and flow on a line is called the PTDF. PTDF is also called sensitivity because it relates the amount of one change transaction amount to another change line power flow. For optimal location of FACTS devices, the prototype for the power flow is considered by plotting PTDF values for corresponding transactions as shown in Figures 4 and 5 for both bus systems. Lines with high slope and lower magnitude are considered good to place FACTS device. For 6 bus systems, based on the prototype formed, it is pragmatic that sensitivity variations are of lower magnitude but with higher variations between lines 4 and 5. Even though it is higher between the lines 1 to 3, the PTDF values are also higher so it is not preferable to place FACTS devices. Therefore for obtaining enhancement the FACTS devices are preferred to be placed between the buses 4 to 5 for UPFC and in the bus 4 for STATCOM.

For 30 bus system, based on the prototype formed in Figure 5, it is pragmatic that sensitivity variations are of lower magnitude but with higher variations between lines 33. The PTDF values are higher. Therefore, for obtaining enhancement the FACTS devices are preferred to be placed between the buses 15-18. So STATCOM is placed in bus 18 and UPFC between buses 15 and 18. Figure 5 shows how, the PTDF value in negative indicates that when the transacted power increases, the corresponding line flow decreases. The PTDF value in positive indicates that when the transacted power decreases, the corresponding line flow increases. The performance of various FACTS devices is compared in Figure 6 for 30 bus system.

For 6 bus system, STATCOM provides 2.19 MW of improvement in ATC, while UPFC provides 6.343 MW of improvement in ATC. In the case of 30 bus system, STATCOM provides 3.528 MW of improvement in ATC when it is placed in bus 18, UPFC provides 8.29 MW of improvement in ATC while incorporating between the lines 15 and 18 for BT1. These values reveals that UPFC performs well compared to STATCOM for ATC enhancement. This is given in Tables 2 and 3 and for all transactions it is visually interpreted in Figure 6.

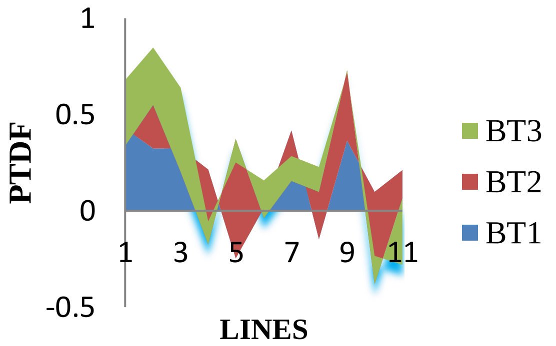

Fig. 4. Placement of FACTS device by ACPTDF for 6 bus system.

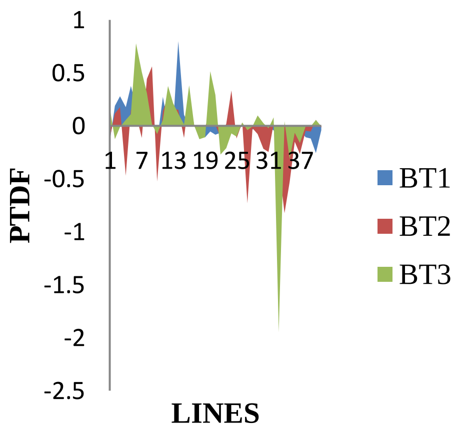

Fig. 5. Placement of FACTS device by ACPTDF for 30 bus system.

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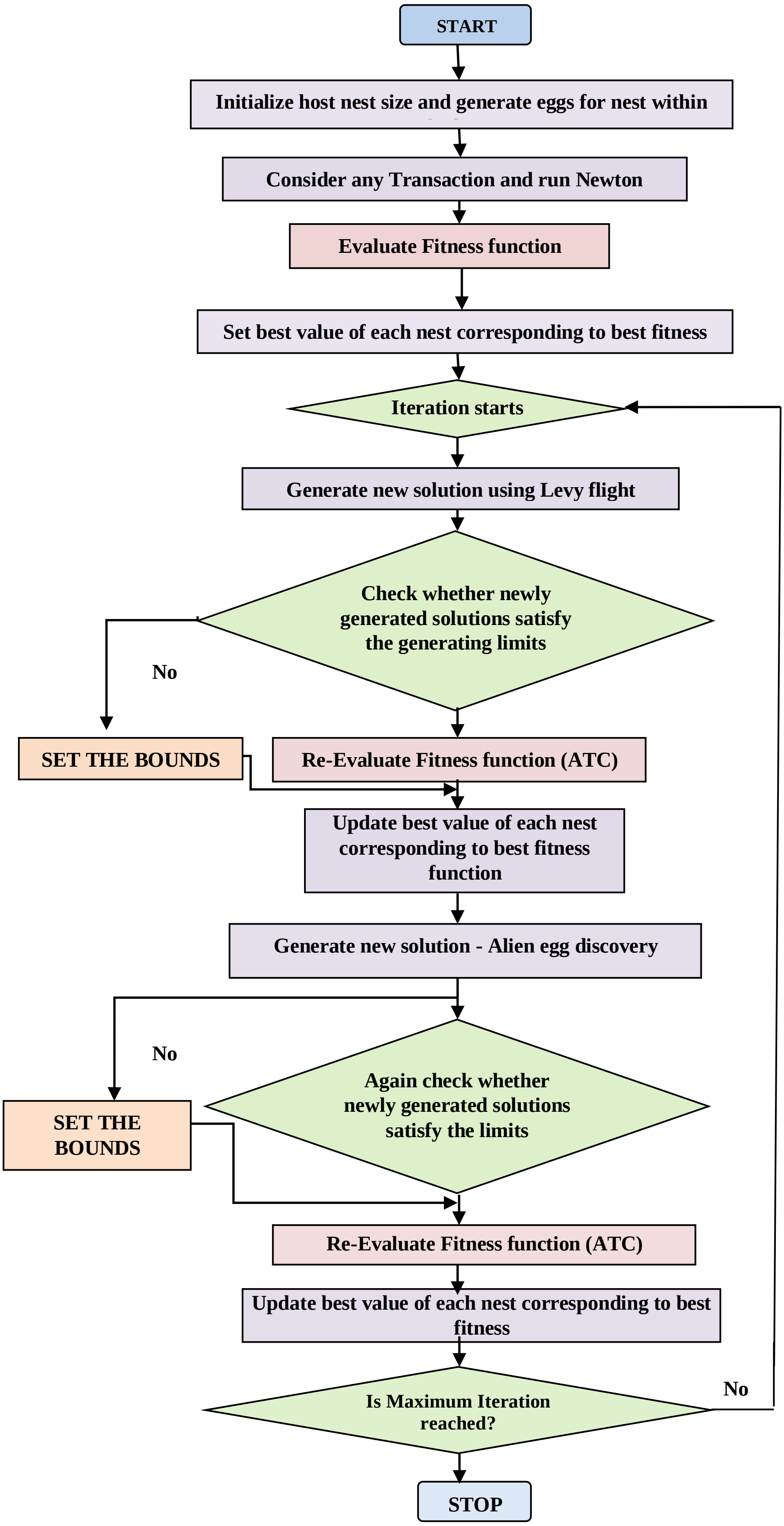

Fig. 3. Flowchart.

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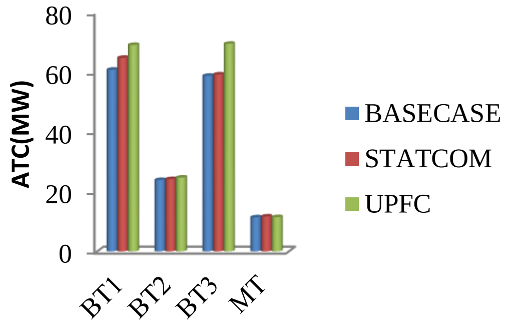

Fig. 6. Comparison of ATC values for 30 bus system.

The Figures 7 and 8 denote the convergence graph obtained for BT1 transaction using STATCOM for 100 iterations. Table 1 shows the parameter settings of the FACTS devices. Table 2 shows the improvement in ATC values using the proposed algorithm for a 6-bus system and for 30 bus system it is shown in Table 3.

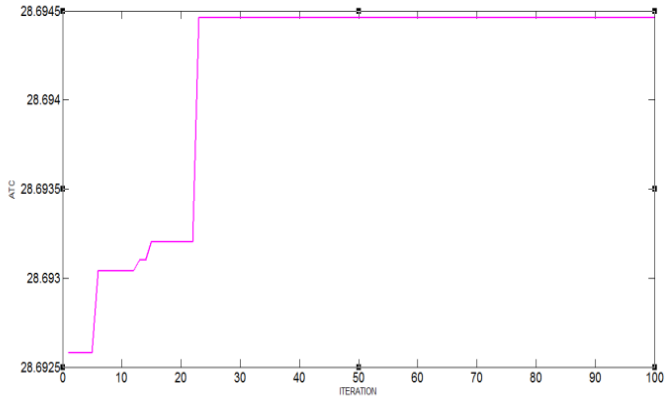

Fig. 7. Convergence graph for BT1 using STATCOM for 6 bus system.

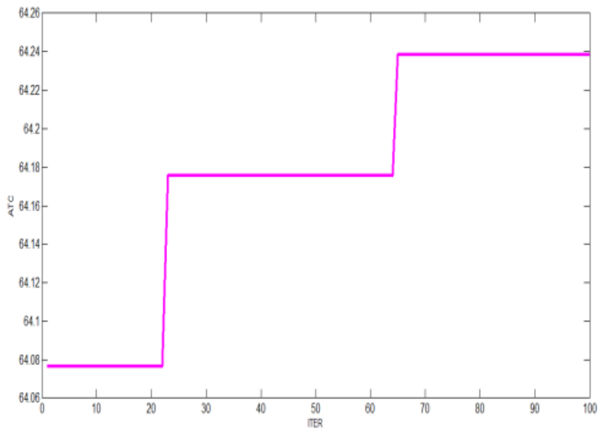

Fig. 8. Convergence graph for BT1 using STATCOM for 30 bus system.

Table 1. Parameter settings of FACTS devices.

STATCOM			UPFC				
V_{sh} (p.u)	$Delta_{sh}$ (rad)	Z_{sh} (p.u)	V_{sh} (p.u)	$Delta_{sh}$ (rad)	Z_{sh} and Z_{se} (p.u)	V_{se} (p.u)	$Delta_{se}$ (rad)
0.9 to 1.1	-0.0843 to 0	0-10j	0.9 to1.05	-0.0843 to 0	0-10j	0.5	-1.5207

Table 2. Enhanced ATC value with STATCOM and UPFC using CSA for 6 bus.

Transaction	Base case ATC (mw)	STATCOM				UPFC			
		ATC (MW)	V_{sh} (p.u)	$Delta_{sh}$ (rad)	X_{sh} (pu)	ATC (MW)	V_{sh} (p.u)	$Delta_{sh}$ (rad)	X_{sh} (pu)
BT1	26.5	28.694	1.039	0.0912	6	35.037	1.0728	0.087643	0.07
BT2	43.289	44.728	1.017	0.0849	5.12	50.962	0.9605	-0.09312	0.129
BT3	33.164	35.392	1.071	0.0891	7.12	35.037	0.9039	0.09326	0.058
MT	32.927	33.931	0.989	0.095	8.13	34.681	0.9255	0.09187	0.0736

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Table 3. Enhanced ATC value with STATCOM and UPFC using CSA for 30 bus.

Transaction	Base case ATC (mw)	STATCOM				UPFC			
		ATC (MW)	Vsh (p.u)	Deltash (rad)	Xsh	ATC (MW)	Vsh (p.u)	Deltash (rad)	Xsh
BT1	60.855	64.239	1.098	0.08796	3.8403	69.145	1.093	0.08658	0.19589i
BT2	23.901	24.047	0.942	0.09191	8.12i	24.725	1.031	0.08729	0.10384i
BT3	58.83	59.27	1.058	0.09198	3.11i	69.55	1.07	0.09340	0.14375i
MT	11.367	11.663	1.072	0.09134	6.723i	11.447	1.035	0.09303	0.10254i

4. CONCLUSION

ATC a vital issue in the field of deregulation is unraveled by calculating it using linear sensitivity factor AC-PTDF method and it is enhanced using FACTS devices like STATCOM, UPFC whose optimal settings of the FACTS parameters like shunt voltage and its angle are attained using Cuckoo Search Algorithm for sample 6 bus and IEEE 30 bus system. The considerable difference between ATC values with and without FACTS devices justifies that the control using FACTS technology and also ensures that it can offer an efficient and shows possible way out to boost the usable power transfer capability, thereby improving transmission services of the competitive electricity market. The proposed methodology is tested in sample 6 bus and IEEE 30 bus system. The results are fairly convincing.

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