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ATC enhancement with FACTS devices using Biogeography Based optimization Technique

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ABSTRACT

Deregulation of electric power industry aims at creating a competitive market and this brings in new challenges in the technical and non technical aspects. One such problem is congestion management which involves relieving the transmission lines off their overloads, which in other words means enhancing the Available Transfer Capacity of the lines(ATC).Determination and Enhancement of ATC are important issues in deregulated operation of power systems.ATC determination for bilateral transaction based on ACPTDF's with FACTS devices is the main objective function. The most popular FACTS devices like SVC, TCSC and UPFC are considered for enhancing the ATC of the interconnected power systems. The optimal location of FACTS devices were determined based on Biogeography Based Optimization (BBO) algorithm. The problem is solved by taking into account the variations in wheeling transactions across any two selected buses and the algorithm is used for enhancing the ATC under various load conditions in an emission economic dispatch environment. The effectiveness of the proposed method is demonstrated on standard IEEE 14, 30 and 57 bus test systems. These systems are loaded starting from base load to 20% of over load and the system performance is observed without and with FACTS devices.

Keywords: Available Transfer Capacity (ATC), Flexible AC transmission system (FACTS) devices, Biogeography Based optimization (BBO),

1. INTRODUCTION

The restructuring of electric power industry aims at creating competitive markets to trade electricity and it generates a host of technical problems that need to be addressed. One of the major requirements of open access environment is the presence of adequate of Available Transfer Capability (ATC) in order to maintain economy and ensure secure operation over a wide range of operating conditions. Various ATC enhancing approaches has been suggested; some of the commonly adopted techniques are to adjust the setting of on load tap changer OLTCS and rescheduling generator outputs.

Flexible AC Transmission systems (FACTS) offer a versatile alternative to conventional methods through increasing flexibility, lower cost, and reduced environment impacts. Flexible AC Transmission systems technology hosts a greater impact over the thermal, voltage and stability constraints of the system. These FACTS devices are used for the power flow control as well as the voltage control with their ability to change the circuit reactance, voltage magnitude and phase angles as control variables to redistribute line flow and regulate nodal voltages thereby mitigations the critical situation. As FACTS devices enable the line loadings to increase even up to their thermal limits they offer a more promising alternative to conventional methods of ATC enhancement

The determination and enhancement of Available Transfer Capability (ATC) in the deregulated power system with Flexible AC Transmission Systems (FACTS) devices such as Static Var Compensator

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(SVC),and Thyristor Controlled series compensator(TCSC), to maximize the power transfer transaction during normal and contingency situations is investigated in (1).The adaptive real coded biogeography based optimization has been suggested in (2) to determine the optimal location and capacity of TCSC and SVC to increase the lodability and boost power transfer capability of the system. The enhancement of Available transfer capability using multi FACTS devices such as Thyristor controlled series capacitor (TCSC) and Thyristor controlled phase angle regulator (TCPAR) based on sensitivity approach has been proposed in (3). Available Transfer capability determination based on Power Transfer Distribution Factors (PTDF'S) and FACTS devices placement through power flow sensitivity analysis is discussed in (4).Genetic algorithm can be used to find optimal location and setting of the combined TCSC and SVC for maximizing ATC and minimizing contingency of power system has been proposed in(5).A Hybrid Immune algorithm for finding the optimal location of Unified Power Flow Controller (UPFC's) for obtaining minimum active and reactive power production cost of UPFC's has been described in(6). In (7) a new approach is proposed for determining the reactive power flows and then evaluate ATC using Power Transfer Distribution Factors..A sensitivity based approach can be used for finding the optimal placement of FACTS devices in a deregulated market has been developed in (8). Biogeography Based optimization (BBO) algorithm can be used for solving economic load dispatch (ELD) problem with generator constraints in thermal plants is presented in (9).A novel Biogeography Based Optimization is proposed in (10) to solve multi constraint Optimal Power Flow (OPF) problem with emission and valve point effect. Multi objective differential evolution has been done for solving Economic environmental dispatch problem is presented in (11). The Flexible AC Transmission system devices are inserted to enhance the single area ATC and multi area ATC by using PSO algorithm is analysed in (12). Hybrid Genetic algorithm and fuzzy logic rules for solving the economic dispatch problem under constrained emission with multi shunt FACTS has been proposed in (13).An Optimal Power Flow based Available Transfer Capability calculation in combined economic emission dispatch environment by using PSO algorithm has been represented in (14).The developed sensitivity factors were utilized for the optimal placement of TCSC'S and TCPAR'S. Two different approaches for the optimal placement of TCSC, one using reactive power loss based sensitivity factor and other using real power flows based sensitivity factor is explained in (15).A hybrid heuristic technique for the optimal placement of TCSC has been suggested by using real coded genetic algorithm along with fuzzy sets has been used for optimizing the complex objective comprising of Available Transfer capability, system voltage profile and device cost(16).Multi area Available Transfer capability using AC Power Transfer Distribution Factors (ACPTDF) and participation Factors (PF) in combined Economic Emission Dispatch (CEED) environment has been proposed in(17). Hybrid mutation Particle swarm Optimization for enhancing Available transfer Capability has been suggested in (18). Biogeography Based Optimization (BBO), a population based algorithm, which uses the immigration and emigration behaviour of the species based on the various natural factors is explained in (19). A new model for combined optimal location of TCPAR and TCSC has been suggested for a pool and hybrid model to enhance the system lodability in (20). AC Distribution factor has been defined for Available Transfer capability calculation under system intact and line outage conditions is discussed in (21).An optimal power flow based FACTS devices placement with an objective of maximizing the power flow across a specified interface is reported in (22).A simple and efficient model for determining the optimal location of FACTS devices in an electricity market by i traducing sensitivity based approach has been developed in (23).

In this proposed work, Available transfer capability is calculated using AC power transfer distribution factor in combined economic emission dispatch environment. Three types of FACTS devices are used in these studies namely TCSC, SVC and UPFC for enhancing the Available transfer capability of the interconnected power systems. The optimal settings of FACTS devices are obtained by using Biogeography Based Optimization. In order to demonstrate the effectiveness of the proposed method, the standard IEEE

14, 30, and 57 bus test systems were considered and an available transfer capability values was computed for all three test systems.

2. AVAILABLE TRANSFER CAPABILITY

Available Transfer Capability ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above the already committed uses. ATC is the difference between TTC and ETC.

ATC = TTC – Existing Transmission Commitments

where TTC is Total Transfer Capability is defined as the amount of electric power that can be transmitted over the interconnected transmission network in a reliable manner while meeting all of a specific set of pre and post contingency conditions.

In order to calculate TTC, thermal, voltage and security limits are also considered.

ATC at base case between bus m and n using line flow limit criterion is mathematically formulated using

$$ATC_{mn} = \min \{T_{ij,mn}\},\ \mathrm{ij} \in \mathrm{NL} \tag{1}$$

Where,

$T_{ij,mn}$ is the transfer limit values for each line in the system.

$$T_{ij,mn} = \begin{cases} \left(p_{ij}^{\max} - p_{ij}^{0}\right) & if\ PTDF_{ij,mn} > 0 \\ \infty(\inf inite); & if\ PTDF_{ij,mn} = 0 \\ \dfrac{\left(p_{ij}^{\max} - p_{ij}^{0}\right)}{PTDF_{ij,mn}}; & if\ PTDF_{ij,mn} < 0 \end{cases} \tag{2}$$

Where,

$P_{ij}^{\max}$ is MW power limit of a line l between buses i and j

P_{ij}^{0} is the base case power flow in line l between buses i and j

$PTDF_{ij,mn}$ is the power transfer distribution factor for the line l between bus i and j when there is a transaction between buses m and n

NL = number of lines

2.1. Ceed Problem Formulation

The Combined Emission Economic Dispatch problem is formulated using the following equation.

$$\phi = \min \sum_{i=1}^{Ng} f(FC, EC). \tag{3}$$

Where,

Φ is the optimal cost of generation in Rs/hr

FC and EC are the total fuel cost and emission cost of generators.

Ng represents the total no. of generators connected in the network.

The cost is optimized following the standard equality and inequality constraints.

$$\sum_{i=1}^{Ng} p_{gi} = p_d + p_l$$

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

Where,

P_{gi} is the power output of the i[th] generating unit.

P_d is the Total load of the system

P_l is the transmission losses of the system.

$p_{gi}^{\min}$ and $p_{gi}^{\max}$ are the minimum and maximum values of real power allowed at generator i respectively.

The bi-objective optimization problem is converted into single optimization problem by introducing price penalty factor h and CEED problem is solved by using evolutionary programming.

2.2. ACPTDF Formulation

The AC Power Transfer Distribution Factor is explained below.

A bilateral transaction t_k between a seller bus m and buyer bus n is considered. Line l carries the part of the transacted power and is connected between bus i and j. For a change in real power transaction among the above buyer and seller by Δt_k MW, if the change in transmission line quality q_l is Δq_l, PTDF is defined as

$$PTDF_{ij,mn} = \frac{\Delta ql}{\Delta t_k} \tag{4}$$

where,

Δt_k = change in real power transaction among the buyer and seller by Δt_k

Δq_l = change in transmission line quality Δq_l.

The transmission quality q_l can be either real power flow from bus i to j (p_{ij}) or real power flow from bus j to i(P_{ij}). The Jacobian matrix for NR power flow is given by

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial V} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \left[J\right]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{5}$$

If only one of the K^{th} bilateral transactions is changed by Δt_k MW, only the following two entries in mismatch vector on the RHS will be non-zero.

$$\left.\begin{aligned} \Delta P_i &= \Delta t_k \\ \Delta P_j &= -\Delta t_k \end{aligned}\right\} \tag{6}$$

With the above mismatch vector element, the change in voltage angle and magnitude at all buses can be computed from (5) and (6) and hence the new voltage profile can be computed. These can be utilized to compute all the transmission quantities q_l and hence the corresponding changes in these quantities Δq_l from the base case.

Once Δq_l for all the lines corresponding to a change in Δt_k is known, PTDF'S can be obtained from the formula.

2.3. Problem Formulation

The objective is to maximize the ATC between the sending and receiving end buses.

$$\text{ATC} = \max \sum_{i=1}^{NL} P_i^{\max} - P_i^{flow}$$

Where,

$p_i^{\max}$ is the thermal limit of the line.

p_i^{flow} is the base case flow of the line

In order to maximize ATC, suitable locations are to be identified and their ratings are to be fixed with FACTS devices by implementing the BBO technique.

3. FACTS DEVICES

Flexible AC Transmission Systems (FACTS) have the ability to allow power systems to operate in a more flexible, secure, economic and sophisticated way. FACTS devices; Alternating current transmission systems incorporating power electronics based and other static controllers to enhance controllability and increase power transfer capability. It may be used to improve the system performance by controlling the power flows in the grid and also used to minimize transmission losses and to improve the voltage profile of the systems.

There are many types of FACTS devices available for power flow control. Among the FACTS devices, TCSC, SVC and UPFC are considered in this work to enhance the power Transfer capability of the System.

3.1. TCSC Modelling

Thyristor Controlled Series Capacitor (TCSC) is a series connected FACTS controller. It is modelled to modify the reactance of the transmission line directly. It may be inductive or capacitive, to decrease or increase the reactance of the transmission line respectively. The TCSC are connected in series with the transmission line in order to improve the power flow through it. The series capacitor also contributes to an improvement in the voltage profile.

The working range of TCSC is considered as follows

$$-0.8X_L \leq X_{TCSC} \leq 0.2\, X_L$$

Where,

X_{TCSC} is the reactance added to the line by placing TCSC

X_L is the reactance of the line where TCSC is located.

The transmission line model with a TCSC connected between the two buses i and j is shown in fig.

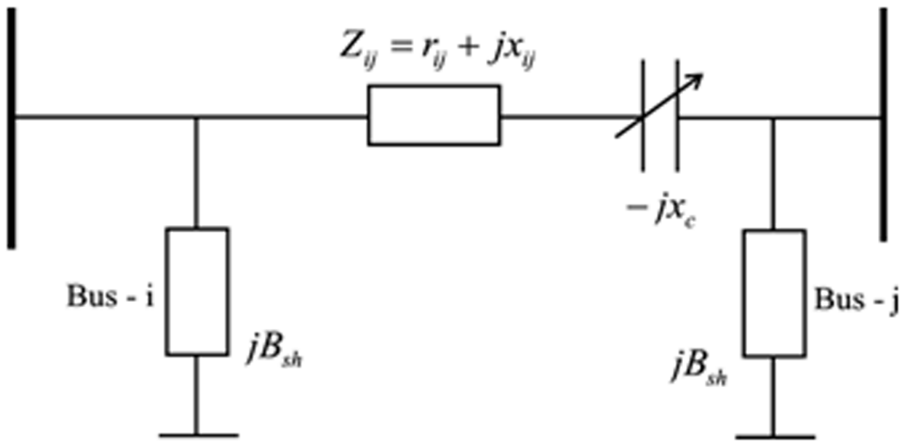

Figure 1: Equivalent circuit of a line with TCSC

3.2. SVC Modelling

The Static Var Compensator (SVC) is a shunt connected FACTS device whose main functionality is to regulate the voltage at a given bus by controlling its equivalent reactance. The SVC may have two characteristics namely, inductive and capacitive. When the system voltage is low, the SVC generates reactive power (SVC capacitive) .when the system voltage is high, the SVC absorbs reactive power (SVC inductive). It is used for voltage control applications. It helps to maintain a bus voltage at a desired value during load variation SVC includes two main components and their combination. Thyristor-controlled and Thysristor-switched Reactor (TCR and TSR) and Thyristor-switched capacitor (TSC) as shown in Fig. (a). Fig.(b).shows the equivalent circuit of the SVC that can be modelled as a shunt connected variable susceptance Bsvc at bus-i.

The working range of SVC is considered as follows

$$-100\text{MVar} \leq Q_{SVC} \leq 100\text{MVar}$$

Where,

Q_{SVC} is the reactive power injected at the bus by placing SVC

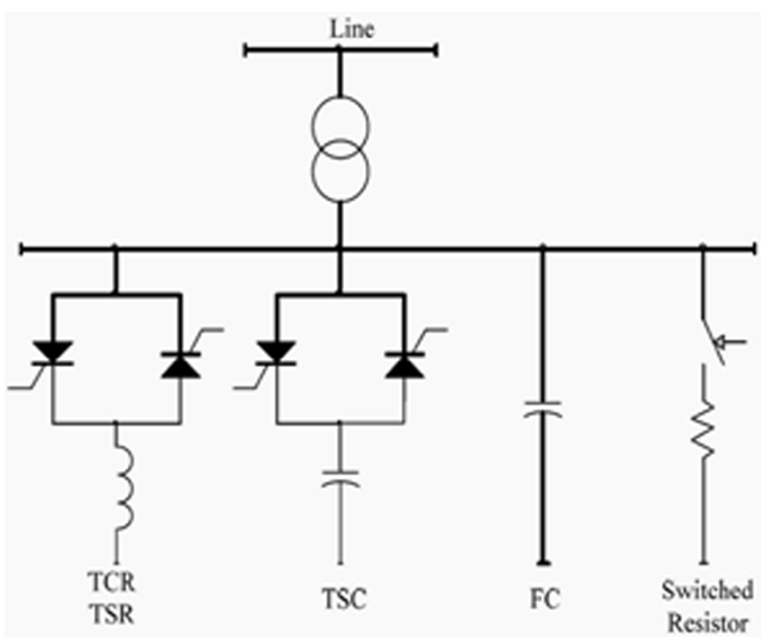

Figure 2: (a) Functional diagram of SVC

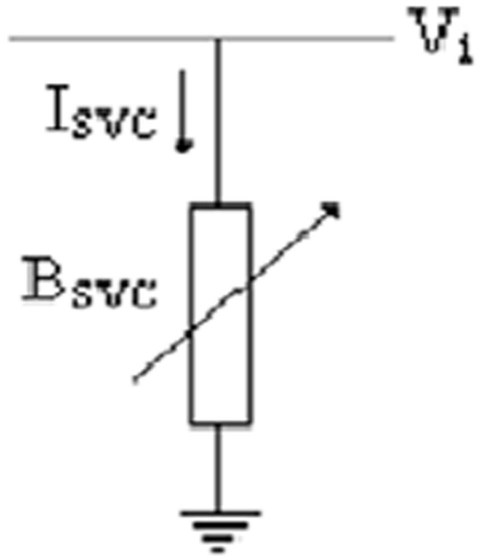

Figure 2: (b) Equivalent circuit of SVC

3.3. UPFC Modelling

Unified Power Flow Controller (UPFC) is one of the most powerful FACTS devices, because it has the ability to control the three parameters of power flow either simultaneously or separately, i.e., transmission angle, terminal voltage and system reactance. It mainly consists of two converters connected by a common DC link. one connected in series with the line through a series injection transformer and another connected in shunt with the line through a shunt coupling transformer. The series controller is used to inject phase voltage with controllable phase angle and magnitudes are in series with line in order to control real and reactive power. Thus the shunt connected controller performs its primary function by delivering exactly right amount of real power required by series controller it also performs its secondary function of generating required reactive power for regulation of the real ac bus voltage. The UPFC offers the unique capability of independently regulating the real and reactive power flows on the transmission lines, while also regulating the local bus voltage.

The UPFC is the combination of STATCOM and SSSC in the transmission line via its d. c link. The shunt controller in the UPFC operates exactly as STATCOM for reactive power compensation and voltage stabilization. The series controller operates as SSSC to control the real power flow and it gives better performance as compared to STATCOM, SSSC and TCSC. The UPFC modelling is shown in fig. 3.

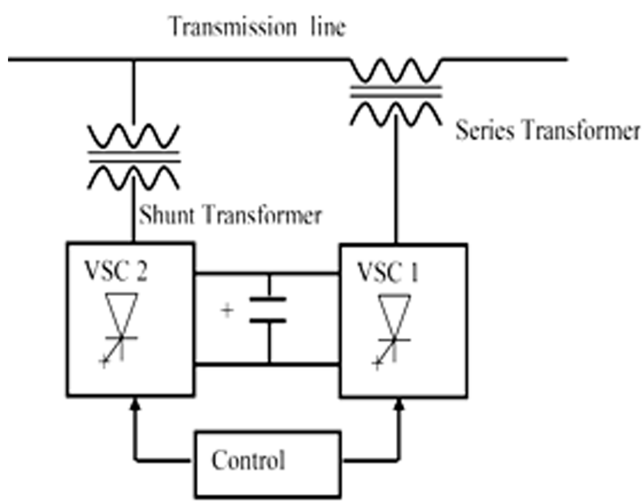

Figure 3: Functional diagram of UPFC

4. OVERVIEW OF BBO TECHNIQUE

Biogeography Based Optimization (BBO) is a population-based, global optimization techniques. It is based on the science of biogeography. Dan Simon proposed Biogeography based optimization technique in 2008.It is used to solve the optimization problem through the simulation of immigration and emigration behaviour of species in and out of habitat .Depends upon the various factors like availability of food, temperature in the habitat, already existing species count in that particular area, diversity of vegetation, and species in that area etc. Based on these factors species moves in and out of the habitats and the process strikes a balance when the rate of immigration is equal to the rate of migration. But these behaviours are probabilistic in nature. A habitat is an island that is physically separated from other islands. A habitat is formed by a set of integers that form a feasible solution for the problem and an ecosystem consists of a no of such habitats. The areas that are well suited as residents for species are said to have high habitat suitability index(HSI).The variable that characterise habitability are called suitability index variables(SIVs). SIVs can be considered the independent variable of the habitat and HIS can be considered the dependent variable.

In BBO solutions with high HSI represents a good solutions and solutions with low HSI represents a bad solutions. The information of habitats probabilistically shares between other habitats using immigration rate and emigration rate of each solution. The immigration and emigration process helps the species in the area with low HSI to gain good features from the species in the area with high HSI and makes the week elements into strong. A set of habitats are generated randomly, it satisfying the constraints and their HSI is evaluated. In order to retain elitism, the best habitat having highest HSI retained without performing migration operation which prevents the best solutions from being corrupted. While the modification process is performed over the rest of the members, HSI is recalculated for the modified ones thereafter mutation operation is carried out over the extremely good and bad solutions leaving aside the solution in the middle range. Stopping criteria is similar to any other popular population based algorithm where the algorithm terminates after a predefined number of trials or after the elapsing of the stipulated time or where there is no significant change in the solution after several successive trials.

BBO algorithm.

1. The system data and the load value are initialized.
2. BBO parameters such as the size of the suitability index variable n, maximum number of iterations, limits of each variable in the habitat are initialized.
3. An initial set of solutions is randomly generated considering the variables to be optimized.
4. The immigration rate λ and emigration rate μ are determined for each of the habitats.
5. Elite habitats are identified and they are exempted from modification procedure.
6. A habitat H_i is selected for modification proportional to its immigration rate λ_i and the source for this modification will be from the habitat H_j proportional to its emigration rate $\mu_{j.}$ This represents the migration phenomena of the species wherein the new habitats are formed through migration.
7. The probability of mutation P_i calculated from λ and μ is used to decide the habitat H_i for mutation and its j^{th} SIV is replaced by a randomly generated SIV.
8. Already existing set of elite solutions along with those resulting from the migration and mutation operations result in a new ecosystem over which the steps 4 to 6 are applied until any one of the stopping criteria is reached.
9. The same procedure is repeated for different load values.

4.1. Algorithm for ATC Enhancement

1. Read the line data, bus data and generator data of the proposed systems.
2. Run the base case optimal power flow (OPF) in the combined emission economic dispatch environment to obtain the base case results.

3. Consider a single wheeling transaction.
4. Compute AC power transfer distribution factor corresponding to the selected .
5. Taking in to account the line flow limits based upon stability and thermal limits, determine the ATC values.
6. Arrange ATC's in ascending order.
7. Fix the type and number of FACTS devices that are to be connected in the system.
8. Run the BBO algorithm to obtain the location and rating of FACTS devices.
9. Calculate ATC values after incorporating FACTS devices namely TCSC, SVC and UPFC.
10. Consider the next wheeling transaction and go to step 4.

5. SIMULATION AND TEST RESULTS

The proposed BBO based optimization techniques has been tested on standard IEEE 14, 30 and 57 bus test systems. A bilateral transaction has been initiated between buses 12 and 13 in a common emission economic dispatch environment and the ratings and locations of FACTS Devices are fixed with an objective of improving the ATC for the above mentioned transaction. The ATC values are obtained through ACPTDF formula and calculated for the particular transaction using the NR Jacobian. The number of FACTS devices has been limited as 3 taking into consideration the cost of the device. The test results for the ATC enhancement problems are given in Tables for IEEE 14, 30 and 57 bus systems.

To study the implementation of FACTS devices for ATC enhancement, the load on the systems were increased in a step by step manner (from base value to 20% of over base value) The improvement in ATC results of the proposed systems with and without FACTS devices can be represented in the Tables 7.1, 7.2 and 7.3 and an equivalent bar chart also represent for all the three systems for various load conditions are represented in Fig. 7.1 to7.3.

Table 1
ATC values for IEEE 14 bus test system

Method	*FACTS Devices*	*ATC values in MW (per line)*				
		Base Load	*5% Over Loaded*	*10% Over Loaded*	*15% Over Loaded*	*20% Over Loaded*
BBO	W/O FACTS	12.52	11.67	10.72	9.74	8.20
	With TCSC	13.02	11.83	11.03	10.06	8.96
	With SVC	13.78	12.74	11.70	10.68	9.13
	With UPFC	16.33	14.94	13.85	12.89	11.79

Table 2
ATC values for IEEE 30 bus test systems

Method	*FACTS Devices*	*ATC values in MW (per line)*				
		Base Load	*5% Over Loaded*	*10% Over Loaded*	*15% Over Loaded*	*20% Over Loaded*
BBO	W/O FACTS	26.87	26.22	25.47	24.66	23.78
	With TCSC	27.52	26.74	26.04	25.10	24.45
	With SVC	27.4	26.92	26.18	25.38	24.43
	With UPFC	28.65	28.03	27.25	26.45	25.38

Table 3
ATC values for IEEE 57 bus test systems

Method	*FACTS Devices*	*ATC values in MW (per line)* Base Load	*5% Over Loaded*	*10% Over Loaded*	*15% Over Loaded*	*20% Over Loaded*
BBO	W/O FACTS	14.94	13.46	12.69	11.51	10.09
	With TCSC	15.20	13.77	13.18	11.91	10.38
	With SVC	15.97	14.62	13.68	12.52	11.55
	With UPFC	17.25	16.38	15.25	14.86	13.74

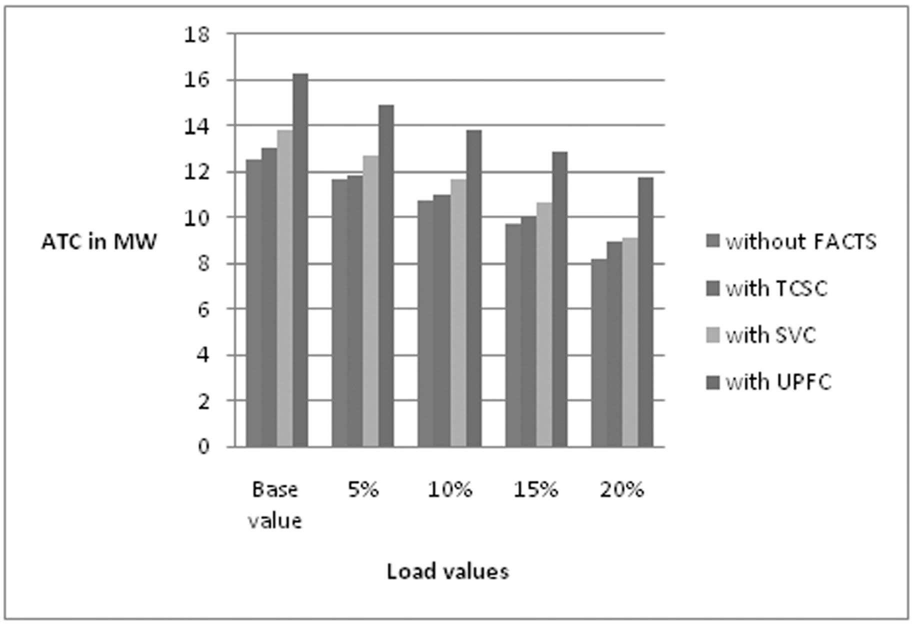

Figure 1: ATC Vs % of Incremental Load for IEEE 14 Bus Test systems (With BBO)

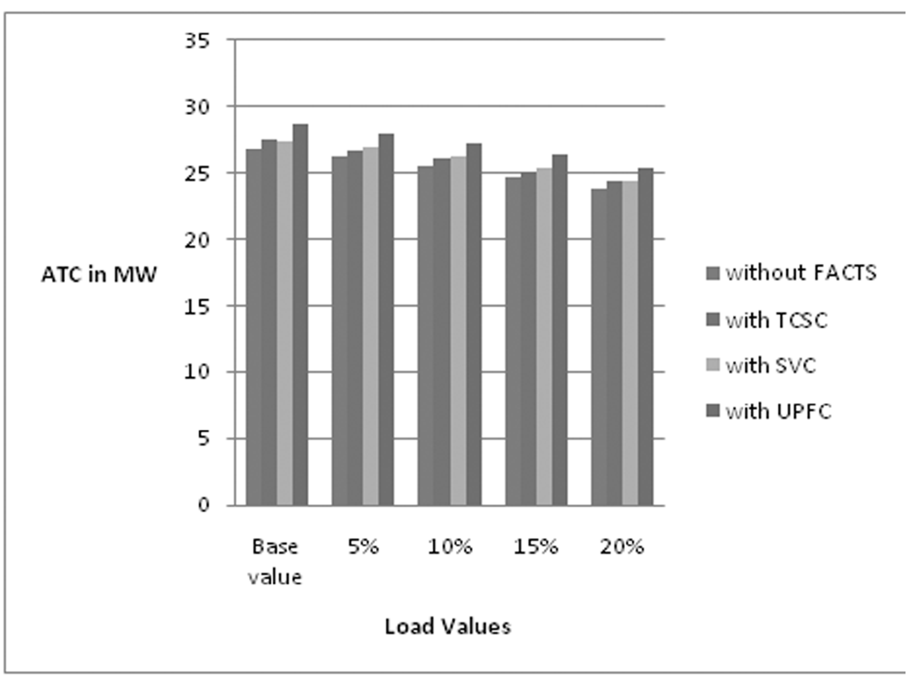

Figure 2: ATC Vs% of Incremental Load for IEEE 30 Bus Test systems (With BBO)

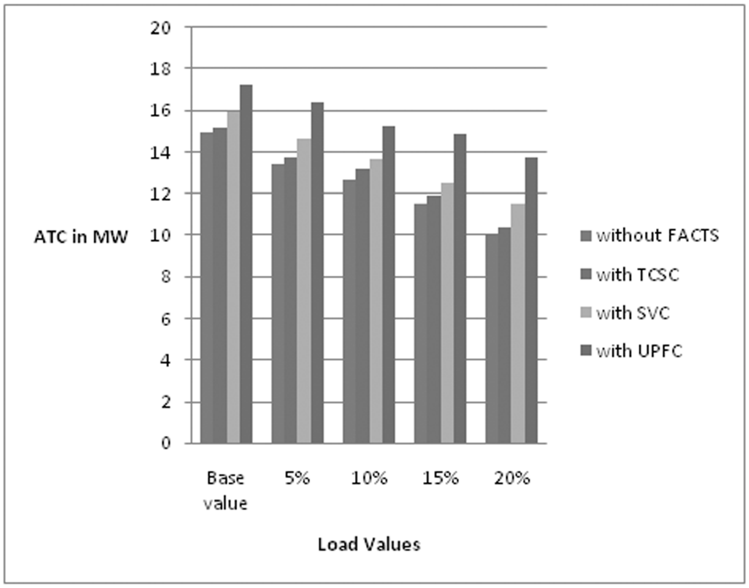

Figure 3: ATC Vs % of Incremental Load for IEEE 57 Bus Test systems (With BBO)

6. CONCLUSION

BBO algorithm has been adopted for solving the problem of ATC enhancement of power system for a bilateral transaction under CEED environment.BBO algorithm simultaneously searches the optimum size and location of FACTS devices under normal and various load conditions. It has been implemented on standard IEEE 14, 30 and 57 bus test systems and for varying the load conditions from 5% to 20% from the base case load.. The results clearly indicate that there is a considerable increase in the ATC of the lines after placing the FACTS devices for the considered bilateral transaction. The BBO is the fast and reliable global search algorithm. It is easy to implement and better to understand. By applying these technique ATC of the systems can be enhanced for any of the wheeling transactions. This enhancement will improve the open access biding and also promote competitive markets for electric power trading.

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