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ATC Enhancement through optimal placement of UPFC using WIPSO 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). In this paper the problem of enhancing the transfer capacity of the transmission lines is addressed by installing UPFC'S through the application of one of the variants of the popular Meta heuristic search technique, Particle Swarm Optimization (PSO) namely Weight Improved Particle Swarm Optimization (WIPSO). 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 and the results are compared against those obtained using PSO.

Keywords-FACTS Devices, Unified power Flow controller (UPFC), Particle swarm Optimization (PSO), Weight Improved Particle Swarm Optimization, Available Transfer Capacity.

1. INTRODUCTION

Deregulation 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 Capacity in order to maintain economy and ensure secure operation over a wide range of operating conditions. There are several approaches to enhance the ATC, some of the commonly adopted techniques are to adjust the settings of OLTCS and rescheduling generator outputs.

With the capability of flexible power flow control and rapid action, Flexible AC Transmission systems technology host a greater impact over the thermal, voltage and stability constraints of the system. With the increase in system loading ATC values ultimately limited by the heavily loaded circuits or nodes with relatively low voltages. FACTS concept uses circuit reactance, voltage magnitude and phase angles as control variables to redistribute line flow and regulate nodal voltages improve thereby mitigations the critical situation.

Bacterial Foraging Optimization based Algorithm (BFOA) is used for maximizing the Available Transfer Capacity and improving contingency is described in (1) and the optimal placement of FACTS devices are used to improve the voltage stability margin of power systems and reduces losses and enhance the ATC under dynamic condition. The Genetic Algorithm (GA) and Differential Evaluation (DE) based algorithm for the optimal allocation of multiple FACTS (Flexible AC Transmission System) devices in an interconnected power systems for the economic operation as well as to enhance the lodability of transmission lines are discussed in (2). The Repeated Power Flow (RPF) technique is used for computing the available transfer capacity. Here, two types of controllers, STATIC Synchronous Compensator (STATCOM) and Unified Power Flow controller (UPFC) are used to enhance ATC to attain the maximum value has been discussed in (3). the optimal location of UPFC for enhancing ATC between the areas has been discussed in (4). A Hybrid Immune Algorithm for finding the optimal location of UPFCs for obtaining minimum active and reactive power production cost of UPFCs has been proposed in (5). A hybrid Meta – heuristic technique for the optimization placement of UPFC and IPFC has been suggested in wherein real coded genetic algorithm along with fuzzy sets has been solving congestion relief problem is discussed in (6). ATC determination based on PTDF's and FACTs devices placement through power flow sensitivity analysis is reported in (7). Bees algorithm used for determining the optimal allocation and parameter setting of FACTs devices such as TCSC, UPFC and TCPST also for maximise the available transfer capacity is reported in (8). Hybrid mutation PSO for enhancing ATC has been proposed in (9). A unified optimization approach is proposed for assessing available transfer capability and solving congestion management problem in deregulated power system without and with UPFC in (10). Multi area ATC determination using ACPTDF's and PF's in a CEED environment has been discussed in (11). Application of PSO technique has been used for the optimal location of FACTs devices are found to minimize the cost of installation of FACTs devices and improve the system lodability has been suggested in (12). The Repeated AC Power Flow based method for enhancing available transfer capacity using UPFC is proposed in (13). Here, the UPFC can be effectively used to overcome some of the limitations to electric power transfer and enable low cost energy to be supplied to the customers. The installation and operation of the FACTs devices for enhancement of steady state security of power systems has been presented in (14) and for achieving proper installation, series compensator are used to control line flows whereas shunt compensator are used to control bus voltages and combined shunt compensator such as UPFC can be employed for controlling both line flows and bus voltages simultaneously. A new real and reactive power coordination controller for a UPFC has been designed and its performance evaluated in (15). AC distribution factor has been defined for ATC determination under system intact and line outage conditions is proposed in (16). A sensitivity based approach has been developed for finding suitable placement of UPFC in a congested system is illustrated in (17). The application of unified power flow controller in inter connected power systems is suggested in (18) in which UPFC control strategy can realize power flow control fairly well and it improve system dynamic performance significantly. A sensitivity based approach has been developed for determining the optimal placement of FACTS devices in an electricity market having pool and contractual dispatches have been proposed in (19). The mathematical model for the UPFC has been proposed for satisfying the regulating power flow through a transmission line and minimizing the power losses without generation rescheduling in (20).

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.

Here it is proposed to calculate ATC using ACPTDF (AC Power Transfer Distribution Factor) in a combined Economic emission dispatch environment and an attempt is going to be made to place the UPFC'S and fix their ratings so as to increase the ATC values. The optimal settings and location of UPFC'S are obtained from WIPSO algorithm.

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 = 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.

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

$$ATC_{mn} = \min \{T_{ij,mn}\},\ ij \in NL \qquad (1)$$

Where,

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

$$T_{ij,mn} = \begin{cases} \dfrac{(P_{ij}^{max} - P_{ij}^{0})}{PTDF_{ij,mn}}; & \text{if } PTDF_{ij,mn} > 0 \\ \infty\,(infinite); & \text{if } PTDF_{ij,mn} = 0 \\ \dfrac{(-P_{ij}^{max} - P_{ij}^{0})}{PTDF_{ij,mn}}; & \text{if } PTDF_{ij,mn} < 0 \end{cases} \qquad (2)$$

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

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

3. CEED PROBLEM FORMULATION

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

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

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

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4. 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_kMW, if the change in transmission line quality $q_l$isΔq_l, PTDF is defined as

$$PTDF_{ij,mn} = \frac{\Delta q_l}{\Delta t_k} \qquad (4)$$

Where,
Δt_k= change in real power transaction among the buyer and seller by Δt_k
Δq_l= change in transmission line qualityΔq_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

$$\begin{pmatrix} \Delta\delta \\ \Delta V \end{pmatrix} = \begin{pmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial v} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial v} \end{pmatrix}^{-1} \begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = (j)^{-1} \begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} \qquad (5)$$

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

$$\Delta P_i = \Delta t_k \qquad (6)$$

$$\Delta P_j = -\Delta t_k$$

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 $\Delta q_l$from the base case.
Once $\Delta q_l$for all the lines corresponding to a change in $\Delta t_k$is known, PTDF'S can be obtained from the formula.

$$PTDF_{ij,mn} = \frac{\Delta q_l}{\Delta t_k}$$

5. ROLE OF FACT 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 may be used to improve the system performance by controlling the power flows in the grid.
There are many types of FACTS devices available for power flow control like, SVC, STATCOM, TCSC, UPFC and phase angle regulator. Among the FACTS devices Unified power flow controller (UPFC) is the most modernised device which can be used to enhance steady state stability, dynamic stability, and real and reactive power flow and so on. The working range of the UPFC angle is between-180° and +180°.

Modelling of UPFC

Unified Power Flow Controller (UPFC) is one of the most powerful FACTS devices, because it has ability to control all the three parameters which affect power flow such as transmission angle, terminal voltage and system reactance. It is designed as two voltage source controllers sharing the same capacitor at their dc voltage controlled side. One voltage source controller is in series with the line through a series injection transformer and another voltage source controller in the UPFC is 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. 5. 1.

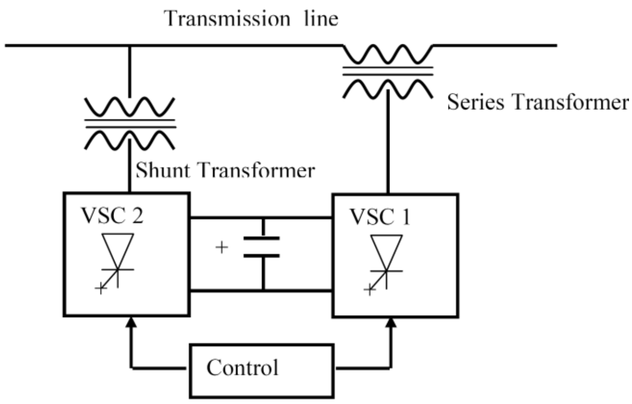

Figure 5. 1. modelling of UPFC Device

6. INTRODUCTION OF PSO

PSO was first introduced by Kennedy and Eberhart in 1995. Heuristic optimization technique introduced by the swarm intelligences of animals such as bird flocking, fish schooling. A swarm of particles represents a solution to the optimization problem. Each particle adjusts its position according to its own experience and the experience of its neighbouring particles. The position and velocity of i^{th}particle in the N – dimensional search space is represented as
$X_i = (x_{i1,} x_{i2,} \ldots\ldots x_{in})$
$v_i = (v_{i1,} v_{i2,} \ldots\ldots v_{in})$
The best position achieved by a particle is recorded and is denoted by
$P_{best\,i} = (x_{i1}^{P_{best}}, \ldots\ldots x_{in}^{P_{best}})$
The best particle among all the particles in the population is represented by

$G_{best\,i} = (x_{i1}^{G_{best}}, \ldots\ldots x_{in}^{G_{best}})$

The updated velocity and position of each particle in $(K+1)^{th}$ step are calculated as follows

$X_i^{k+1} = X_i^k + V_i^{k+1}$

Where,

$V_i^{k+1} = wV_i^k + C_1 rand_1 \; (x_i P_{best\,i}^k - x_i^k) \; + C_2 rand_2 \; (GP_{best\,i}^k - x_i^k)$

x_i^k = Position of individual i at iteration k

X_i^{k+1} = Position of individual i at iteration k + 1

v_i^k = Velocity of individual i at iteration k

W = weight parameter

C_1 = Cognitive factor

C_2 = Social factor

$P_{best\,i}^k$ = best position of individual i until iteration k

$G_{best\,i}^k$ = best position of group until iteration k

$rand_1, rand_2$ = random numbers between 0 and 1.

In this velocity updating process, the acceleration coefficients C_1, C_2 and weight parameter 'w' are predefined and $rand_1$ and $rand_2$ are uniformly generated random numbers in the range of [0, 1].

7. WEIGHT IMPROVED PARTICLE SWARM OPTIMIZATION

To get a better global solution, the algorithm is improved by adjusting the weight parameter, cognitive and social factors. The velocity of the individual using WIPSO is rewritten as

$$V_i^{k+1} = W_{new} V_i^k + C_1\, rand_1 (p_{best\,i}^{\;k} - x_i^k) + C_2\, rand_2 (G_{best\,i}^{\;k} - x_i^k)$$

Where,

$$W = w_{max} - \left\{ \frac{w_{max} - w_{min}}{Iter_{max}} \right\} x Iter$$

$$W_{new} = (\text{Wmin}) + (\text{W x rand}_3)$$

$$C1 = C_1 \max - \left\{ \frac{C_{1max} - C_{1min}}{Iter_{max}} \right\} x\; Iter$$

$$C2 = C_2 \max - \left\{ \frac{C_{2max} - C_{2min}}{Iter_{max}} \right\} x\; Iter$$

w_{min}, w_{max} = initial and final weights

C_{1min}, C_{1max} =initial ad final cognitive factors

C_{2min}, C_{2max} = initial and final social factors

$Iter_{max}$ = maximum iteration number

Iter = current iteration number

$rand_3$ = random numbers between 0 and 1

ALGORITHM

1. Choose the population size, the number of generations, w_{min}, W_{max}, C_{1min}, C_{1max}, C_{2min}, C_{2max}, pbest, gbest. (Population size 20, no. of generations 50)
2. Initialize the velocity and position of all particles randomly, ensuring that they are within limits. Here the individuals represent the real power generation of generator buses in the system.
3. Set the generation counter t=1.
4. Evaluate the fitness for each particle according to the objective function.
5. Compare the particle's fitness function with its $P_{best\,i}$. If the current value is better than $P_{best\,i}$, then set $P_{best\,i}$ is equal to the current value. Identify the particle in the neighborhood with the best success so far and assign it to Gbest.
6. Update velocity by using the global best and individual best of the particle.
7. Update position by using the updated velocities. Each particle will change its position.
8. If the stopping criteria is not satisfied set t=t+1 and go to step 4. Otherwise stop.

8. PROBLEM FORMULATION

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

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 the placement of UPFC and their ratings are to be fixed.

ALGORITHM FOR ATC ENHANCEMENT

1. Read the system input data.
2. Run the base case load flow in the combined emission economic dispatch setting of generators.
3. Consider the wheeling transaction t_k alone.
4. Compute AC power transfer distribution factor.
5. Taking in to account the line flow limits based upon Stability and thermal limits, determine the value of ATC.
6. Arrange ATC in ascending order.
7. Fix the number of UPFC's that is to be connected in the system.
8. Run the PSO algorithm to obtain the location and rating of UPFC's.
9. Calculate ATC after incorporating UPFC's.
10. Consider the next wheeling transaction t_k and go to step 4.

9. SIMULATION AND TEST RESULTS

The proposed UPFC placement algorithm using PSO and WIPSO 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 UPFC are fixed with an objective of improving the ATC for the above mentioned transaction. The ATC values are obtained through ACPTDF calculated for the particular transaction using the NR Jacobian. The number of UPFC's 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 14, 30 and 57 bus systems.

To study the implementation of UPFC for ATC enhancement, the load on the system were increased in a step by step manner. The improvement in ATC results of the system with and without UPFC can be represented in the Tables 9. 1, 9. 2 and 9. 3 and an equivalent bar chart also represent for all the three systems for various load conditions are represented in Fig. 9. 1 to 9. 6. The results have also been obtained by WIPSO technique for comparisons.

Table 9. 1 IEEE 14 Bus Test Systems

ATC in MW	Without UPFC					With UPFC				
	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded
PSO	14.07	12.09	15.81	14.96	18.82	115.43	105.57	132.40	122.21	146.16
WIPSO	16.66	18.39	15.83	18.89	18.09	133.92	144.80	130.83	145.69	146.01

Table 9. 2 IEEE 30 Bus Test Systems

ATC in MW	Without UPFC					With UPFC				
	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded
PSO	26.89	27.31	27.84	28.17	28.64	93.65	93.96	96.80	98.44	100.94
WIPSO	26.93	27.42	27.89	28.25	28.58	93.09	94.28	96.91	99.00	100.96

Table 9. 3 IEEE 57 Bus Test Systems

ATC in MW	Without UPFC					With UPFC				
	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded
PSO	13.16	17.63	13.57	16.53	17.57	127.73	181.13	173.12	183.38	178.72
WIPSO	14.68	15.91	14.98	17.47	16.31	132.64	142.91	167.71	165.81	195.14

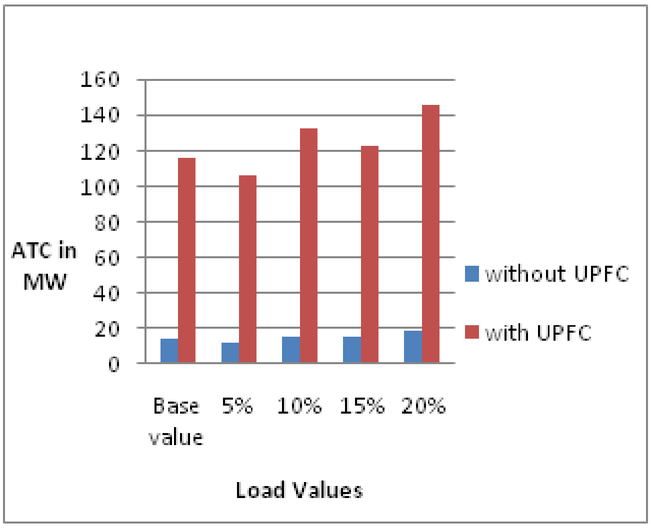

Fig. 9. 1 Bar chart for IEEE 14 Bus Test systems (PSO)

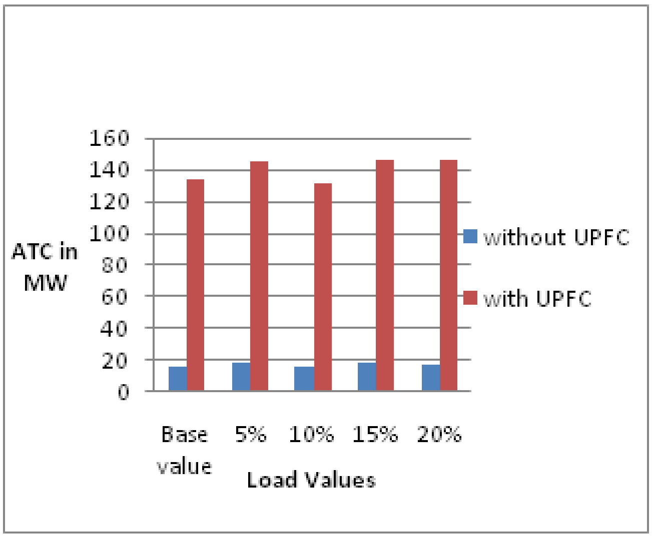

Fig. 9. 2 Bar chart for IEEE 14 Bus Test systems (WIPSO)

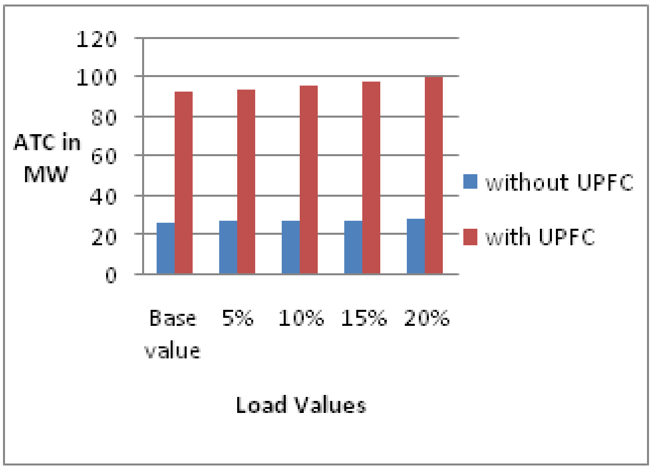

Fig. 9. 3 Bar chart for IEEE 30 Bus Test systems (PSO)

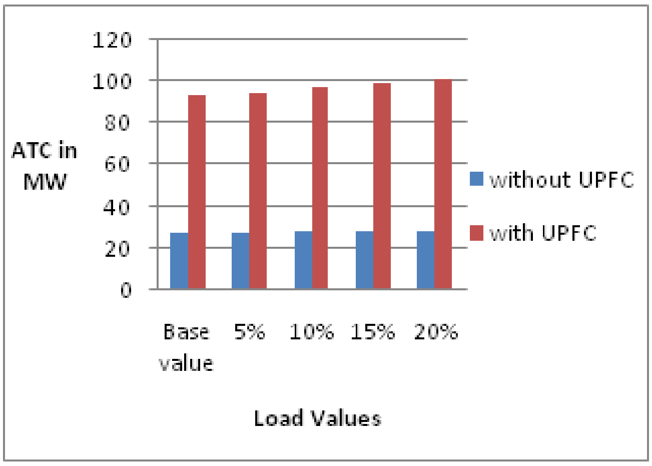

Fig. 9. 4 Bar chart for IEEE 30 Bus Test systems (WIPSO)

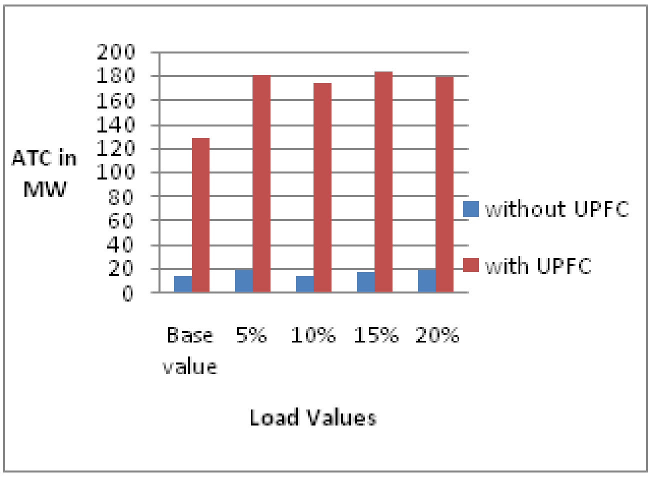

Fig. 9. 5 Bar chart for IEEE 57 Bus Test systems (PSO)

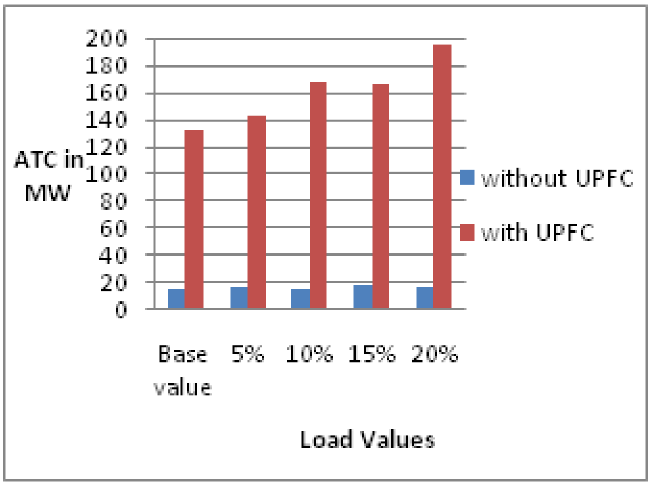

Fig. 9. 6 Bar chart for IEEE 57 Bus Test systems (WIPSO)

10. CONCLUSION

In this paper an ATC enhancement technique for a bilateral transaction under CEED environment has been proposed wherein WIPSO technique has been used for choosing the optimum size and location of UPFC under various loading conditions. The results obtained were compared against those obtained using PSO technique. The results clearly indicate that there is a considerable increase in the ATC of the lines after placing the UPFC and due to the fact that the weight parameter, cognitive and social factors are adjusted in WIPSO to obtain a better global convergence, it shows a comparatively better performance than PSO. By applying this technique ATC of the systems can be enhanced for any of the wheeling transactions and a combination of devices may be used for a more flexible enhancement.

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