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Differential Evolution Algorithm For Computation of ATC in Deregulated Power System

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ABSTRACT

The restructuring process of the electrical industry throughout the world aims at creating competitive markets to trade electricity. The major issue in the restructuring process is to compute the value of Available Transfer Capability (ATC). In this paper, Differential Evolution Algorithm (DEA) is used to determine the optimal value of ATC for normal operating condition and line outage condition. The proposed method is tested on IEEE 24 bus Reliability Test System (RTS) and IEEE 118 bus system.The DE based method has achieved solutions with good accuracy and satisfactory computation time.The results are compared with Repeated Power Flow (RPF) method and the comparison shows the superior performance of DE based approach for ATC computation.

Key words: Available Transfer Capability, DifferentialEvolution, Repeated Power Flow, NRLF

1. INTRODUCTION

With the introduction of competition in the power industry all over the world, the electricity supply industries are forced to utilize their network facilities in a more economic and secure manner [1]. Under this scenario, the determination of ATC has emerged as a new measure for secure and reliable operation of a system. ATC is definedas the additional power that can be transmitted through a specified interface over and above the already committed transactions [2]. Mathematically, ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM). Mathematically it is written as,

$$\text{ATC} = \text{TTC} - \text{TRM} - (\sum \text{ETC} + \text{CBM}) \tag{1}$$

For the sake of simplicity, TRM and CBM are assumed to be zero.

The information of ATC will help market participants to reserve transmission services well in advance for optimal commercial use of transmission network.There are several methods and tools available in the literature to calculate ATC.

Christie et. al. [3] proposed a techniquebased on DC load flow for ATC estimation. This method is easy and computationally fast, but voltage and reactive poweris not taken into consideration. Due to the approximations involved in DC power flows, AC Power Transfer Distribution Factor (ACPTDF) [4] method has gained importance. Ajjarapu et. al. [5] proposed Continuation Power Flow (CPF) for ATC computation. This method involves predictor, parameterization, corrector and step-size control as discussed by Chiang

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et. al.[6]. The CPF, in spite of its popularity has the disadvantage of complex mathematical computations.Repeated Power Flow (RPF), repeatedly solves power flow equations at a succession of points along the specified load generation increment asdiscussed in reference [7].This method is iterative in nature andso it takes more time to estimate ATC for large systems.

Recently, evolutionary computation techniques such as Genetic Algorithm [8] and Particle Swarm Optimization (PSO) [9] have been applied to calculate the ATC values. Both Genetic Algorithm and PSO suffer fromcomputational burden and memory. Also, the prematureconvergences degrade their performance and reduce itssearch capability. This paper proposes a Differential Evolution Algorithm (DEA) for ATC Calculation. DE [10-11] is anevolutionary algorithm that uses rather greatly selection andless stochastic approach to solve optimization problems thanother evolutionary algorithms. The main features of DE are itssimple structure, convergence property, quality of solution androbustness. It is used for solving complex constrained non-linear optimization problem. DE uses the difference of randomly sampled pairs of object vectors to guide the mutation process which makes it relatively new when compared to other algorithms. The effectiveness of the proposed approach hasbeen demonstrated through IEEE RTS 24 Bus system and IEEE118 Bus system.

2. PROBLEM FORMULATION

As stated in section I, ATC is defined as the additional power that can be transmitted through a specified interface over and above the already committed transactions.The problem of ATC computationin bilateral transaction can be formulated as an optimization problem in which the objective is to maximize the difference between TTC and ETC without violating theconstraints. This is stated as maximize

$$F = P_{Di}^{new} - P_{Di}^{old} \tag{2}$$

P_{di}^{new} New change in load demand of i_{th} sink bus from its base case load.

P_{di}^{old} Base case load demand of i_{th} sink bus

Subject to,

Real power balance equation

$$P_i - V_i \sum_{j=1}^{N_B} V_j \left[G_{ij} \cos\theta_{ij} - B_{ij} \sin\theta_{ij} \right] = 0 \quad i = 1, 2 \ldots. N_{B-1}$$

Reactive power balance equation

$$Q_i - V_i \sum_{j=1}^{N_B} V_j \left[G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right] = 0 \quad i = 1, 2 \ldots. N_{PQ}$$

Slack bus real power generation limit

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

Generator reactive power generation limit

$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}$ i€N_{PV}

$\Delta P_{Di} = \Delta P_{Gk}$

$V_{\min} \le V \le V_{\max}$

$S_{ij\min} \le S_{ij} \le S_{ij\max}$

G_{ij}, B_{ij} Conductance and Susceptance of transmission line Connected between i_{th} and j_{th} bus.

P_i, Q_i Real and Reactive power injection of i_{th} bus.

P_s Real power generation of slack bus.

Q_{gi} Reactive power generation at bus i.

N_{PV} Number of voltage buses.

N_B Total number of buses.

N_{PQ} Number of load buses.

$N_{B\text{-}1}$ Total number of buses excluding slack bus.

ΔP_{GK} Change in generation of source bus from its base case value

V_{min} Minimum voltage limit in all the buses

V_{max} Maximum voltage limit in all the buses

S_{ij} MVA limit of all branches

3. OVERVIEW OF DIFFERENTIAL EVOLUATION ALGORITHM

Differential Evolution is a population-based stochastic search algorithm that works in the general framework of evolutionary algorithms.The working of DE is similar to that of Genetic algorithm (GA) except mutation process. In GA, mutation is carried out by changing the genes but in DE, the mutation is carried out on the arithmetic combinations of the randomly generated or best individuals from the whole population. Thevarious operations of DE are initialization, mutation, crossover and selection. The various process of DE is given below.

3.1. Initialization

The first step of DE optimization process is initialization of population. In initialization process all candidates are randomly generated as a real valued number within its corresponding feasible bounds using the expression

$$x_{i,j}^{G} = x_i^{\min} + r \text{ and } {}_i[0, 1]*(x_i^{\max} - x_i^{\min}),\ \text{i} = 1, \ldots, D \text{ and } j = 1, \ldots.., NP \tag{3}$$

Where NP is number of population and D is number of decision parameter of the problem. $x_i^{\min}$ and $x_i^{\max}$ are the lower and upper bounds of the ithdecision parameter, respectively.rand$_i$[0,1] represents a uniformly distributed random value in the range [0, 1]. Once every vector of the population has been initialised, its corresponding fitness value is calculated and stored for future reference.

3.2. Mutation

During mutation, three random vectors are selected from current population. The mutation is carried out on randomly selected vector X_{r1}^{G} with the difference of two other randomly selected vectors X_{r2}^{G} and X_{r3}^{G}. The mutation vector is generated using the formula (4)

$$V_i^{G} = X_{r1}^{G} + F*(X_{r2}^{G} - X_{r3}^{G}) \tag{4}$$

Where F is scaling factor, which is typically chosen from within the range [0, 1].

3.3. Crossover

The next step of DE optimization process is crossover. In this step, by applying crossover operation between target vector and mutant vector a trial vector is created according to a selected probability distribution

$$U_i^{(G)} = U_{j,i}^{(G)} = \begin{cases} V_{j,i}^{(G)} if & rand_j(0,1) \le CR \\ X_{j,i} otherwise & 0rj = s \end{cases} \tag{5}$$

The crossover constant *CR* is a user-defined value (known as the “crossover probability”), which is usually selected from within the range [0, 1]. The crossover constant controls the diversity of the population and aids the algorithm to escape from local optima. rand_j is a uniformly distributed random number within the range (0, 1) generated anew for each value of j. s is the trial parameter with randomly chosen index $\{1,\ldots, D\}$, which ensures that the trial vector gets at least one parameter from the mutant vector.

3.4. Selection

Selection is final operation of DE procedure. This operator compares the fitness of the trial vector and the corresponding target vector and selects the one that provides the better solution. This selected vector is then treated as target vector for next generation.

$$X_i^{(G+1)} = \begin{cases} U_i^{(G)} if \cdot f(U_i^{(G)}) \le f(X_i^{(G)}) \\ \qquad X_i^{(G)} otherwise \end{cases} \tag{6}$$

The feature of DE selection scheme is that a trial vector is comparedwith only one individual, not all the individuals in the currentpopulation.

4. DE IMPLEMENTATION DETAILS

When applying DE to calculate the ATC, two main issues need to be addressed:

(a) Representation of the decision variables and

(b) Formation of the Fitness function

4.1. Variable Representation

Each individual in the genetic population represents a candidate solution. For calculatingATC, the change in new load demand of sink bus value (P_{Di}^{new}) is taken as a decision variable.This variable is represented as floating point numbers in the DE population. The lower and upper bound for decision variable aretaken as1, (ATC^{max}) respectively. In this work ATC^{max} is taken as 1000.

4.2. Fitness Function

Evaluation of the individuals in the population isaccomplished by calculating the objective function value forthe problem using the parameter set. The result of theobjective function calculation is used to calculate the fitnessvalue of the individual. Fitter chromosomes have higherprobabilities of being selected for the next generation. The fitness function is given below.

$$ATC = P_{Di}^{new} - P_{Di}^{old}$$

5. ALGORITHM FOR ATC EVALUATION

The detailed steps for calculating ATC using DE is given below:

The proposed DE solution for ATC problem is composed of the following steps

1. Read bus data, generator data, branch data and Specify the transaction for whichthe ATC has to be computed.
2. Read data for DE operations i.e. maximum generation limit, number of population, the change in new load demand of sink bus value as the decision Variable, lower and upper limit of decision variable, scaling factor F, Crossover rate.

3. Set generation Gen = 0.
4. Generate population randomly according to Eq. (3), where decision variable is within its feasible bound.
5. Compute ATC using Eq. (2) for each population of parent vector
6. Initialize the iteration iter = 1
7. For each iteration do the following steps

a. Set the parent population with the maximum value P_{Di}^{new} is the target vector i

b. Perform mutation and crossover according to Eq. (4) and (5) and get trail vector.

c. Selection among the target and trial vector for the survival using Eq. (6).

d. Using selected best vector value compute ATC and check for any operating Limit violation.

e. If any limit is violated increase the iteration iter = iter + 1, repeat again from step (b), till the process get converged. If does not converge the population has reinitialized automatically, otherwise go to next step.

f. Best vector selected will be the next parent vector for the nextPopulation.

8. Increment the generation gen = gen + 1
9. Check the maximum generation limit , if yes go to next step, otherwise go to step 4
10. Print the corresponding selected best vector as the optimum value of P_{Di}^{new}
11. Compute ATC using Eq. (2)

6. SIMULATION RESULTS

This section presents the details of the simulation study carried out on IEEE RTS 24 busand IEEE 118 bus system for ATC computationat normal operating condition and line outage condition using the proposed approach. The data for IEEE RTS 24 bus and 118 bus systems are taken from [15]. The Thermal limit and voltage limits are considered as constraints, the reactive power demand at load bus is assumed to be increasing as a percentage of realpower increase. The simulation studies were carried out by developing Matlabprogram and by using Mat power 4.1 software. The results obtained by proposed approach are compared with RPF results to justify its accuracy. The computation of RPF method is given in Appendix II.

6.1. ATC Estimation in IEEE RTS 24 Bus System

The IEEE RTS 24 bus system consists of 11 generator buses, 13 load buses and 38 transmission lines. The transactions considered here are T_1 (23-3),

T_2 (21-10), T_3 (22-3) and T_4 (18-10).

The best result of the DE was obtained with the following control parameters:

No. of generations:	50
Population size:	100
Crossover probability:	0.5
Mutation factor:	0.7

6.1.1. Normal operating condition

The ATC values for different transactions under normal operating condition using the proposed approach are given in Table1. The results are compared with the results of RPF method. Table1 also shows limiting element for all transactions.

Table 1
ATC values under normal operating condition

Transaction No.	*Transaction*		*ATC(MW)*		*Limiting element*
	Source Bus	*Sink Bus*	*RPF method*	*DE method*	
T1	23	3	118.55	117.60	The voltage magnitude at 3rd bus
T2	21	10	344.80	343.78	Thermal limit of line 14-16
T3	22	3	120.55	119.58	The voltage magnitude at 3rd bus
T4	18	10	341.20	340.09	Thermal limit of line 14-16

From this Table1,it is observed that, the ATC values calculated by the proposed approach are very close to the values obtained using RPF method. The algorithm took 10 sec for convergence.

6.1.2. Line Outage (3-9)

In this case, the line connected between bus 3 and bus 9 is removed and corresponding ATC values are computed using the proposed approach. Table2shows the values of ATC obtained for the same bilateral transactions with line outage condition. The results are also compared with RPF results.

Table 2
ATC values with line outage of 3-9

Transaction No.	*Transaction*		*ATC(MW)*		*Limiting element*
	Source Bus	*Sink Bus*	*RPF method*	*DE method*	
T1	23	3	55.80	55.23	The voltage magnitude at 3rd bus
T2	21	10	306.00	306.53	Thermal limit of line 14-16
T3	22	3	58.95	57.98	The voltage magnitude at 3rd bus
T4	18	10	303.65	302.50	Thermal limit of line 14-16

From Table 1 and 2 it is observed that ATC values for line outage condition has reduced compared to the non-outage condition. The limiting elements of ATC for alltransactions are also given in the above table.

6.2. ATC Estimation in IEEE 118 Bus Systems

The IEEE 118 bus system consists of 54 generator buses, 64 load buses and 186 transmission lines. The line flow limits for IEEE 118 bus system are given in appendix III. The bilateral transactions considered here are, T_1(1-118), T2(46-80), T3(49-100) and T_4(54-75).

The best result of the DE was obtained with the following control parameters:

No. of generations:	50
Population size:	150
Crossover probability:	0.5
Mutation probability:	0.7

6.2.1. Normal Operating Condition

The ATC values obtained for the different bilateral transactions under normal operating condition using the proposed approach are given in table 3. The results are compared with the results of RPF method. Table 3 also shows limiting element for all transactions.

Table 3
ATC values under normal operating condition

Transaction	*Transaction*		*ATC(MW)*		*Limiting element*
No.	*Source Bus*	*Sink Bus*	*RPF method*	*DE method*	
T1	1	118	37.45	36.45	The voltage magnitude at 118th bus
T2	46	80	390.15	389.14	Thermal limit of line 81-80
T3	49	100	375.90	374.92	Thermal limit of line 81-80
T4	54	75	147.30	146.31	The voltage magnitude at 118th bus

From this table, it is observed that, the ATC values calculated by the DE method are very close to the values obtained by RPF method. The computation time taken by this method is 30 seconds only and it'slesser compared with RPF method.

6.2.2. Line Outage (76-118)

In this case, the line connected between bus 76 and bus 118 is removed and corresponding ATC values are computed using DE approach. The table 4shows obtained ATC values for bilateral transaction with line outage condition. The results are compared with RPF results. The limiting element of ATC for all transactions is also given in this table.

Table 4
ATC with line outage of 76-118

Transaction	*Transaction*		*ATC(MW)*		*Limiting element*
No.	*Source Bus*	*Sink Bus*	*RPF method*	*DE method*	
T1	1	118	30.10	29.26	The voltage magnitude at 118th bus
T2	46	80	374.60	373.56	Thermal limit of line 81-80
T3	49	100	360.90	359.93	Thermal limit of line 81-80
T4	54	75	116.30	115.35	The voltage magnitude at 118th bus

From table 1, 2, 3 and 4 it is observed that ATC obtained by DE is much closer to the RPF results. Hence this proposed approach is suitable for computing ATC in deregulated environment.

7. CONCLUSION

This paperhas presented the application of DE for computation of ATC under normal operating condition and line outage. The ATC computation has been tested on IEEE RTS 24 bus and IEEE 118 bus system.The obtained results are compared with the RPF results. Test results shows that the proposed DE based approach provides accurate value of ATC. Test results also shows that for large system like IEEE 118 bus system the ATC estimation using DE based approach takes less time than RPF method. In a real time operation of deregulated power system, the ISO has to estimate ATC values for many possible proposed transactions with in short time. As, DE based approach can estimate ATC value in short time with good accuracy, the ISO can use DE based approach for ATC estimation. Thus the proposed approach provides significant profit to all the market participants in the electricity market.

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APPENDIX I

Computation of ATC Using RPF Algorithm

The procedure for calculating ATC using RPF algorithm is given below:

- Specify the transaction for which the ATC has to be computed.
- Run AC power flow for the given base case state.
- Increase the sink bus load and source bus injection by the same amount

  With large steps and run power flow.
- Repeat Power Flow till the operating limit violation occurs.
- Decrease the transaction by the minimum amount necessary to eliminate the Violation and repeat power flow with smaller steps. The reason for running the Simulation in a larger step at the first stage and with smaller steps in the second Stage is to reduce the time consumption and to increase the accuracy.
- The maximum possible increase in demand which causes no operating

  Limit violation is the ATC.

APPENDIX II

Line Flow Limits For IEEE 118 Bus Systems

Line Code	*Power flow limits (MW)*
1-6,10-12,14-20,22-30, 34, 35, 37,39-49,52, 53,55-89, 92, 101, 105, 106,109-111,113-115, 117, 118,120-122, 125, 126,128-132136, 140,143-162,164-173,175-179	200
7,9,13,21,31,33,38,50,90,91,94,96-100,103,104108, 112, 116, 119, 123, 124, 133, 134,137-139141, 142, 163,174	800
8,32,36,51,54,93,95,102,107,127,135	1000