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EVOLUTIONARY ALGORITHM FOR CALCULATING AVAILABLE TRANSFER CAPABILITY

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The paper presents an evolutionary algorithm for calculating available transfer capability (ATC). ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. In this paper, MATLAB software is used to determine the ATC between any bus in deregulated power systems without violating system constraints such as thermal, voltage, and stability constraints. The algorithm is applied on IEEE 5 bus system and on IEEE 30 bus system.

K e y w o r d s: power systems, available transfer capability (ATC), genetic algorithm (GA), power transfer distribution factor (PTDF), symbolic analysis

1 INTRODUCTION

The concept of competitive industries rather than regulated ones has become prominent in the past few years. Economists and political analysts have promoted the idea that free markets can drive down costs and prices thus reducing inefficiencies in power production. This change in the climate has fostered regulators to initiate reforms to restructure the electricity industry to achieve better service, reliable operation, and competitive rates.

In deregulated power systems, transmission networks are subjected to various bilateral service contracts between customers and suppliers. A bilateral transaction can be represented by a source (positive injection) connected to the point of injection and a sink (negative injection) connected to the point of extraction. The source and the sink are assumed to be of the same size and that the other generation and consumption of the system remains unchanged. In the issue of bilateral transactions, available transfer capability (ATC) can be used as an indicator of relative system security and the profits made in these bilateral power transactions.

ATC is a measurement of the transfer capability remaining in the physical transmission network for further commercial activity, over and above already committed uses. The reasoning behind the development of ATC is based on several principles developed by the North American Electric Reliability Council's (NERC) [1].

The techniques used to obtain the ATC can be classified as one step [2–6] and iterative [7–9] method. An ac-PTDF method for calculation of ATC is proposed in [5]. Reference [6] takes into account flow of reactive power while keeping the restrictions that are defined for DC method. In [7] for determination of ATC has been used Quasi-Steady-State approach on radial network, while production and consumption have increased in steps up to stability disruption. A Continuation Power Flow is used in [8] and ATC is calculated only between certain nodes with predetermined optimal FACTS devices location. After the determination of optimal FACTS devices location, ATC was calculated based on the PTDF's [9].

This paper is organized as follows. Section 2 describes one step method for ATC calculation. Section 3 provides a brief description of basic concepts of Genetic Algorithm. Section 4 describes the proposed algorithm. Section 5 shows the computation results analyzing two cases. Section 6 summarizes the conclusions of our work.

2 ATC CALCULATIONS BASED ON DC POWER FLOW

One step calculated ATC, ATC calculated based on DC power flow, which represents the theoretical maximum value of power that can be transmitted between two nodes, can be calculated in several ways. In [2], ATC is calculated using the PTDF's which are obtained by multiplying the ordinary Jacobian matrix and the Jacobian matrix with respect to flows. In [3], ATC is calculated using the PTDF's which are obtained with the corresponding elements of reactance matrix. In [4], the PTDF's are obtained with symbolic calculations. Using any of these approaches, the results are the same. The authors have chosen the third approach, which will be briefly described.

With SADCLF program whose detailed description is presented in [10], and the application in [11] and [4], the equations of the line power flow in symbolic form are generated and have the following form

$$P_{lk} = \sum_{i=1}^{n} a_{lk,i} P_i \tag{1}$$

where P_{lk} is active power flow on the line lk, n is total number of power system nodes, $a_{lk,i}$ is shift factor for

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line lk and node i which was obtained using DC load flow. P_i is a nodal active power injection

$$P_i = P_{gen\,i} - P_{load\,i} \tag{2}$$

where $P_{gen\,i}$ is active power generation at node i, and $P_{load\,i}$ is power demand at node i.

Power transfer distribution factor (PTDF) is calculated for a particular transaction. To calculate the PTDF it is necessary to sum up the appropriate shift factors which are determined by the node number of participants of observed transaction. These coefficients are calculated for each line of the power system for observed transaction and have the following form

$$ptdf_{lk\,ij} = a_{lk,i}\text{sign}\{P_i\} + a_{lk,j}\text{sign}\{P_j\}\,. \tag{3}$$

The subscripts lk indicate for which line the coefficient is calculated, and the subscripts ij are related to observed transaction (where i indicates node where the seller is and j indicates node where the buyer is), sign is the signum function. Since power injection (ΔP) is at node i it follows that

$$P_i = \Delta P - 0 \tag{4}$$

while extraction of the same amount of power is done at node j, so that

$$P_j = 0 - \Delta P\,. \tag{5}$$

Substituting expressions (4) and (5) into (3), the following is obtained

$$ptdf_{lk\,ij} = a_{lk,i} - a_{lk,j}\,. \tag{6}$$

The PTDF of some line is a percentage of power that will flow through that line as a consequence of the establishment of considered transaction.

For the ATC calculation it is necessary to know the power flows on network lines and thermal limitations of the system elements. Knowing these values, the available loading capacity could be determined [1]

$$ALC_{lk} = P_{t,lk} - P_{lk} \tag{7}$$

where ALC_{lk} is the line lk available loading capacity, $P_{t,lk}$ is the line lk thermal limit, P_{lk} is the line lk active power flow. The maximum power transfer between the two nodes in the power system (the maximum power of transaction), at which the observed line reached its thermal limit, is calculated as follows

$$P_{trans\,ij,lk} = \frac{ALC_{lk}}{ptdf_{lk,ij}} \tag{8}$$

where $P_{trans\,ij,lk}$ is maximum power of transaction between nodes i and j at which power flow of line lk reaches its maximum. ATC represents the minimum thus calculated power of transactions, namely

$$ATC_{ij} = \min_{\substack{l=1,\dots,n\\ k=1,\dots,n}} P_{trans\,ij,lk} \tag{9}$$

where ATC_{ij} is maximum power of transaction between nodes i and j that can be safely transmitted through the power system.

ATC once calculated in this way can be stored in memory and later used as needed. So with the change of power system elements or power of production/consumption it is simply need to replace symbols with corresponding numeric value. In order to proceed with further work it is necessary to replace the symbols with numbers. It is important to note that with this method of calculation of ATC gets the same results as in the manner described in the references [2] and [3]. This value of ATC represents the theoretical maximum value of transmission between two points of the power system, and therefore this is the upper limit for the variable which will be used in genetic algorithm, whose description follows.

3 GENETIC ALGORITHM

The genetic algorithm is a random search method that can be used to solve nonlinear systems of equations and to optimize complex problems. The principle of this algorithm is according to the selection of individuals. It does not need a good initial estimation for the sake of problem solution. In other words, the solution of a complex problem can be started by weak initial estimations and then be corrected in an evolutionary process of fitness.

The standard genetic algorithm manipulates the binary strings, called population, which may be the solutions of the problem. Solutions from one population are taken and used to form a new population. This is motivated by a hope that the new population will be better than the old one. Solutions which are selected to form new solutions (offspring) are elected according to their fitness the more suitable they are the more chances they have to reproduce.

This algorithm can be used to solve many practical problems such as optimal switch allocation [12], optimal sizes and locations of shunt capacitors in radial distribution network [13], switching angles of the cascaded inverter for reduction of harmonics [14], optimal motion planning for a golf swing robot [15], optimal power flow [16], etc. The genetic algorithm generally includes the three fundamental genetic operators of elitism, crossover and mutation. These operators conduct the chromosomes (strings) toward better fitness.

There are two methods for coding the variables in the genetic algorithm [17]:

– Binary codification, and
– Decimal codification.

Conventional binary codification of variables for genetic algorithm has been used in this paper.

In order to accelerate genetic algorithm it is very important that all the chromosomes of the initial population are feasible. This means that each randomly generated chromosome which represents a potential solution to the problem must satisfy all the defined constraints. If single constraint is not exceeded chromosome is retained, otherwise are discarded and generate new one. The process is repeated until the entire population is feasible. At the start this slow down the algorithm because of constant needs for checking the feasibility of each chromosome, but the algorithm with the initial population formed in this way converges much faster than without it.

3.1 Elitism

Elitism is usually the first operator applied on a population. It selects a predetermined number of chromosomes with best fitness in current population and copies them directly into the new population. This helps in preventing loss of good individuals, and very rapidly increase performance of genetic algorithm [18].

3.2 Crossover and mutation

Crossover operator is applied next to strings of the current population. There exist a number of crossover operators in the genetic algorithm literature. Almost all crossover operators take randomly two chromosomes from the current population and mix some parts of chromosomes to provide offspring. In [19] there are detailed explanation of the three types of crossover: the one point crossover, the two point crossover and the one point substring crossover. In this paper the one point crossover has been used, and can look like this (| is a randomly chosen crossover point):

Chromosome 1	**1011100**|**1000110**
Chromosome 2	1100110|0011111
Offspring 1	**1011100**0011111
Offspring 2	1100110**1000110**

Crossover operator is mainly responsible for the search of genetic algorithm, even though mutation operator is also used for this purpose sparingly. Mutation is a way to give a new piece of information to an individual, as well as to prevent falling of all solutions in population into a local optimum of the solved problem. It represents an accidental bit variation of an individual, generally with a constant probability for each bit within a population. The mutation probability can further vary depending on the size of the population, application and preferences of the explorer [17], or be a fixed value, which is often kept during the whole genetic algorithm is used for each generation [20].

In this paper, in an effort to speed up the algorithm the number of chromosomes to be mutated is reduced with the passage of iterations. Number of chromosomes in each iteration on which the mutation is applied is subject to the following principles [17]

$$n\_mut = N\_mut\left(1 - r^{(1-t/T)^b}\right) \tag{10}$$

where n_mut is the number of chromosomes in current iteration of which a mutation will be performed, N_mut is the number of chromosomes on which a mutation in the first iteration was performed, r is a random number from 0 to 1 (in our case $r = 0.1$), t is the number of the current iteration, T is the maximum number of iterations (generations), b is a system parameter determining the degree of dependency on iteration number (we used $b = 2$).

In the later iterations operation of mutation is only allowed on bits which are far from the beginning of the string. This property causes this operator to search the space uniformly initially (when t is small), and very locally at later stages; thus increasing the probability of generating the new number closer to its successor than a random choice.

Every offspring resulting from the above operators, crossover and mutation, must be verified whether it is feasible. One generation is completed after generating entire feasible new population.

3.3 Selection

Chromosomes are selected from the population to become parents in crossover operation. In this paper the authors used two methods of random selection of chromosomes, roulette wheel selection and rank selection. The selection for crossover was performed by roulette wheel selection for first parent and with rank selection for second parent. The authors have decided for such a selection in order to avoid problems [18] that would have occurred if it is chosen only one way of selection.

4 PROPOSED ALGORITHM

The method of the proposed algorithm is as follow

Step 1

- Prepare the database for the generator data, bus data, shunt data, transformer data and transmission line data.
- Initialize parameters: population size (N), maximum number of generations (T), elitism rate, crossover rate and mutation rate.
- Run optimal power flow for given conditions.
- Calculate ATC with DC method for obtaining the maximum theoretical value of transmission for all transactions.
- Set generation count $gen\_count = 1$.

Step 2

- Choose nodes which will define the transaction participants.
- For the selected transaction generate arbitrary initial population, whose members are transmission power (P_i, $i = 1, \ldots, N$) between nodes of selected transaction.
- Run power flow using the Newton-Raphson method for each member of the population.
- If an element of the population exceeds any specified limit (bus voltage violation, bus voltage phase angle, real and reactive power limits at all generator buses,

Table 1. Control parameters

Control parameters	Definition
$N = 20$	Population size
$T = 100$	Maximum number of generations
$el\_rate = 0,1$	Elitism rate
$cros\_rate = 0,7$	Start crossover rate
$mut\_rate = 0,2$	Start mutation rate

Table 2. Power of production and consumption for 5 bus system

Node	1	2	3	4	5
P_{gen} (MW)	120	40	0	0	0
P_{load} (MW)	0	20	45	40	60

Table 3. ATC calculated with one step method

	Buyer				
Seller	1	2	3	4	5
1		76.6102	102.7273	96.1702	82.1818
2	279.3220		352.0000	286.8750	132.4454
3	374.5455	301.3333		148.0645	164.8370
4	311.0526	369.3750	190.6452		176.3372
5	291.6818	280.2183	290.6557	344.2657	

thermal violation for all lines), such elements are discarded and generate the new one.

- The process is repeated until all elements of the initial population are feasible.

Step 3

The fitness of each chromosome is

$$F_i = P_i, \text{ for } i = 1, \ldots, N \tag{11}$$

where F_i is the fitness value of function for i-th chromosome, P_i is the value of transmission power of selected transaction for i-th chromosome.

Step 4

From the current population select as many of the best elements as defined by elitism rates and copy them into the new population.

Step 5

- Selection of parents for crossover operation. Method of selection was described in the previous section.
- Randomly determine an intersection point for one point crossover which was used in this paper.
- For obtained offspring calculate power flow using the Newton-Raphson method.
- Test all offspring of defined limits, as described in step 2.
- If they are feasible, the offspring are kept in the new population, and if not they are discarded and procedure is repeated.
- The procedure described in this step is repeated until it reaches a predetermined number of elements of the new population, which is defined by the crossover rate.

Step 6

- With the mutation operation the remaining elements of the new population are filled.
- For obtained offspring calculate power flow using the Newton-Raphson method.
- Test all offspring of defined limits, as described in step 2.
- If they are feasible, the offspring are kept in the new population, and if not they are discarded and procedure is repeated.
- Procedure described in this step is repeated until the new population is filled with feasible elements.

As the number of chromosomes to be mutate reduces over time, and there is a need for a constant number of elements of the population, deficiency in a population that arose as a consequence of this reduction has been completed with the crossover operation.

Step 7

Increment the generation count gen_count by 1. If $gen\_count < T$, go to step 3. Otherwise find the best individual among population and display the result.

Table 1 presents the significant parameters which characterizes this algorithm. Start crossover rate and start mutation rate in Tab. indicates how many percent of the total population each of these two operations will be produced in the first iteration. In the following iterations the number of chromosomes that will be mutated is reduced by the principle which is given by equation (10). And since there is a need for the unchanged number of elements of the population, deficit which would occur in the population as a result of the reduced number of chromosomes that are mutated are filled with the offspring who are the result of crossover operation.

5 TESTS AND RESULTS

The proposed model has been applied to IEEE 5 bus system [21], and the IEEE 30 bus system [16]. All problems have been solved using the code developed in MATLAB on a Pentium dual-core 2.1 GHz.

For the first example standard IEEE 5 bus system is used, with adopted thermal limits of 150 MW on all lines. This network, although small, in reality may present points of systems/areas interconnections. It was also chosen because it is possible to represent all possible combinations of transactions between the areas in the table. The power of production and consumption that are necessary to calculate ATC with one step method are given in Tab. 2. The results obtained with one step method are shown in Tab. 3. As mentioned in second chapter values in Tab. 3 represent the theoretical maximum value of the power transfer between any two areas.

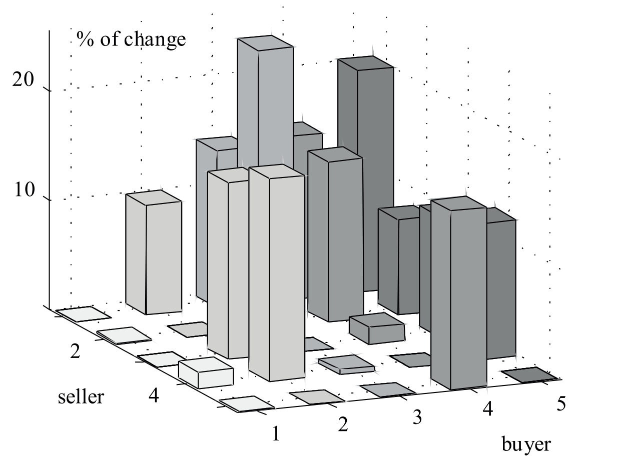

Fig. 1. Percentage of change in the value of the ATC when the voltage limits are respected

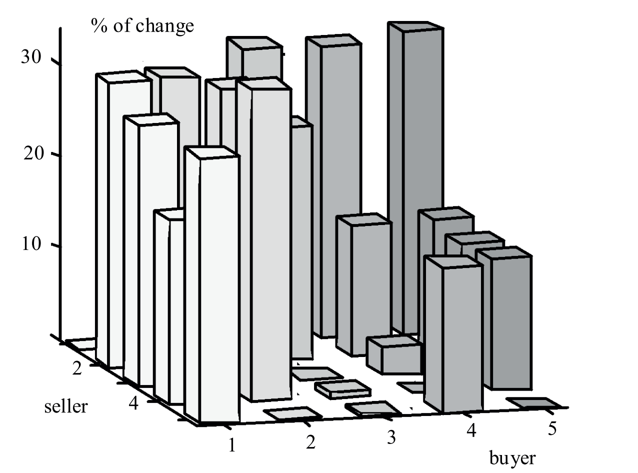

Fig. 2. Percentage of change in the value of the ATC when all limits are respected

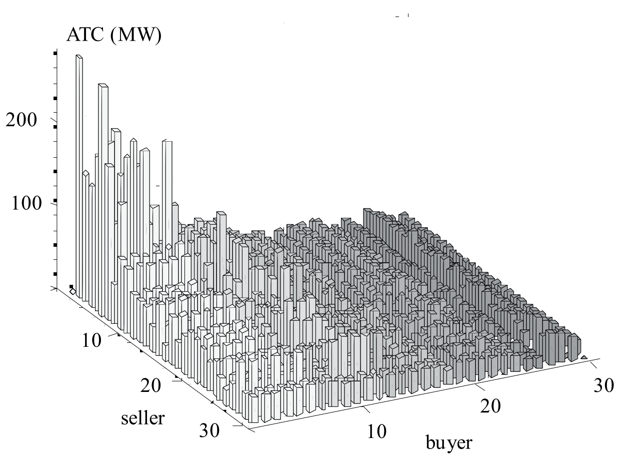

Fig. 3. ATC obtained with one step method

Table 4. ATC calculated in relation to restriction of bus voltage angle and amplitude constraints

	Buyer				
Seller	1	2	3	4	5
1		68.9320	88.0367	81.8115	65.4965
2	278.9129		262.1100	244.8851	120.9397
3	374.5455	252.6570		145.7417	146.6986
4	306.1889	300.8622	189.8539		154.2930
5	291.6457	280.2173	290.6546	288.0231	

Table 5. ATC calculated with respect to all constraints

	Buyer				
Seller	1	2	3	4	5
1		54.2004	69.7806	65.4990	55.0667
2	192.1516		262.8844	245.7223	113.1581
3	267.3028	204.7448		143.4375	141.9684
4	248.1289	243.4627	189.6677		150.9190
5	206.6468	280.2077	290.0160	289.4720	

Using the proposed algorithm with respect to the bus voltage constraints ($0.95 < V_i < 1.05$, where $i = 1, \dots$ is the number of system buses), bus voltage phase angle limitations and thermal constraints, two experiments were done. In the first experiment the thermal limits of lines are compared only with the flow of active power through lines. And in the second experiment the flow of reactive power through power system lines is taken into consideration. The results of these two experiments are shown in Tables 4 and 5.

Observing the results presented in these tables, a significant impact of the flow of reactive power through power system lines on the ATC value can be noticed. For example, Table 3 entry for the transaction from 5 to 2 yields 280.2183 MW as the theoretical maximum transfer between these two areas. Comparing this result with the one shown in Tab. 4, 280.2173 MW, it can be seen that the voltage constraints has little impact on this transaction. When the flow of reactive power through power lines is taken into consideration, results shown in Tab. 5, the maximum value of power that can be transmitted with this transaction is 280.2077 MW. By observing just this introductory example one could come to the wrong conclusion that the ATC calculated with one step method gives fairly accurate results.

To confirm this statement it is enough to compare the results of analysis for the transaction 1–5. The theoretical maximum power that can be transferred is 82.1818 MW, Tab. 3. Taking into account the voltage limitations, the ATC value for this transaction drops to 65.4965 MW, Tab. 4. Finally with respect to the flow of reactive power through power system the value of ATC decreases to 55.0667 MW, Tab. 5.

Figures 1 and 2 show the percentage change in the value of ATC calculated in experiments compared to the values of ATC calculated with one step method. Figure 1 show the case when the bus voltage limitation was considered. Figure 2 shows the case when the flow of reactive power was taken into account. From these figures it could be concluded that the flow of reactive power substantially affects the value of ATC and should be taken into account when calculating.

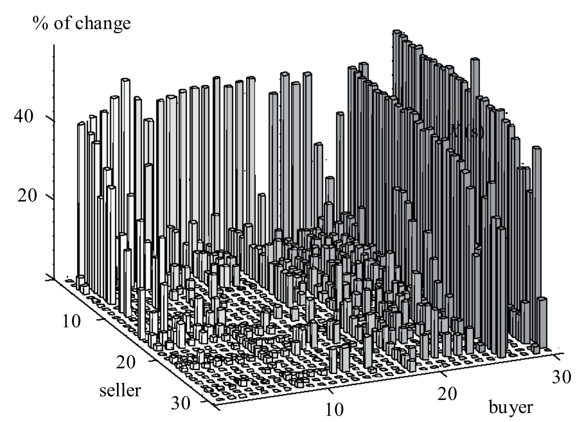

Fig. 4. Percentage of reduction of ATC caused by voltage limits

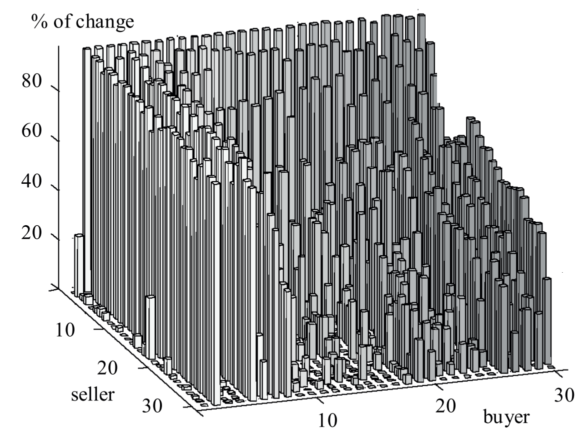

Fig. 5. Percentage of reduction of ATC when all limits are respected

For the brevity the results for IEEE 30 bus system are presented with figures rather than using the table. Figure 3 shows the value of ATC calculated with one step method. In Fig. 4 due to large dimensions of power system impact of voltage limitation is much more visible. Taking into account only this limitations maximum error in the first example was 25 %, and in second example was 60 %. Figure 5 shows percentage of reduction of the value of ATC when all constraints are considered.

Let us assume that consumers at node 2, where a local generator is situated, decide to purchase electrical energy from the bus 28 (also, this is a point of interconnection with other system). The value of ATC obtained with one step method is 61.7086 MW, Fig. 3. With addition of only voltage limitations the value of ATC is 61.4525 MW, which represents a decrease of only 0.415 %, Fig. 4. When all limitations are taken into account the value of ATC falls by 95 %, Fig. 5, *ie* between these two nodes a maximum of 2.7 MW can be transmitted.

The time required to calculate the ATC value for a single transaction in the first example was 2.8 s, while for larger network needs 24.08 s per transaction. Due to the time rise with the increase of the network, and the need to use algorithm in real time some simplifications are necessary. For example, as sellers buses should be considered only those buses that are attached to generators or to the other systems via interconnection line because only those buses have the possibility of procurement of electric energy. If the purchase is available only at certain nodes this can lead to further acceleration of the algorithm. However it is not advisable to reduce whole network model for the sake of algorithm acceleration because the information of congestion lines that affect the value of ATC may be lost.

6 CONCLUSIONS

In this paper, a method for calculating the value of ATC which is a combination of one step DC method and improved genetic algorithm is shown. The one step DC method calculates the theoretical maximum value of power that can be transferred between any two points in power system. The value of ATC obtained in this way is used as an input parameter for the genetic algorithm. Improvement of genetic algorithm is reflected in the operation of mutation on the binary representation of variables. This improvement has resulted in faster convergence of the proposed method. The algorithm is tested on two standard systems, IEEE 5 bus system and IEEE 30 bus system.

The simulation results show the effectiveness of genetic algorithm method in calculating the ATC value, and enlarge the possibilities of implementation of the algorithm in real time.

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