Simultaneous ATCs Determination Using Pareto Based Evolutionary Programming Technique

S. Ilias, M.M.Othman, I. Musirin, A. Mohamed and A. Hussain

Abstract — **This paper presents a new approach to determine simultaneous available transfer capability (ATC) for two transfer cases. Simultaneous determination of power transfer for two or more transfer cases involved intricate ATC calculations that yield to a lengthy computational time. Therefore, the Pareto based evolutionary programming (EP) is used to overcome the intricacy in calculating the optimum value of ATC with a fast computational time. The multi-objective function for the Pareto based EP technique is the ATC for two transfer cases and power flow limitation is considered as the fitness function of EP. The effectiveness of Pareto based EP technique in determining the ATCs are validated based on a case study of IEEE 24 bus system. The ATC is determined for the transfer cases from selling areas 1 and 2 to a buying area 3 and also from selling areas 1 and 3 to a buying area 2.**

Index Terms — **Available transfer capability, Pareto based evolutionary programming technique, multi-objective function.**

I. INTRODUCTION

In a deregulated power system, available transfer capability (ATC) computation has become a key component to all companies that participate in the power transfer activities. Due to open transmission access, electric utilities are required to produce commercially viable information of transfer capabilities of their transmission systems so that such vital information can help power marketers, sellers and buyers in planning, operation and reserving the transmission services [1]. There are two significant indices in the transfer capability assessment, namely, the total transfer capability (TTC) and the available transfer capability (ATC). By definition, TTC represents as the maximum amount of power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre- and post-contingency system conditions [2]. On the other hand, ATC is a measure of the additional amount of power that may flow across the interface, over and above the base case flows without jeopardizing the power system security [3].

A predetermined set of ATC values can be accessed by electricity market participant and system operators through an open access same-time information system (OASIS) [4]. Concurrently, posting the transfer capability signal incurred within a limited time requires fast computational method in estimating the accurate ATC value. Simultaneous determination of power transfer for two or more transfer cases is mathematically complicated which inhibits fast computation time in estimating the ATCs. Most methodologies only addressed specific power transfer from one selling area to one buying area. The methodologies are such as the DC power flow [1], AC power flow [5], optimal power flow [6] and sensitivity [7]. The method based on linear DC power flow considering distribution factors is considered fast but less accurate for transfer capability analysis because the DC network model does not require the voltage magnitude and reactive power component in the power flow calculation. Therefore, the linear DC power

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flow may result in optimistic ATC value especially for the heavily stressed system that caused by critical contingency. The AC power flow method gives an accurate solution in determining the ATC because it considers the effects of reactive power flows and voltage limits. Simultaneous determination of power transfer for two or more transfer cases is rarely discussed. [1]Presently, there are not many papers discussed on the optimization algorithm that used to estimate multi-objective function of ATC or power transfer for two or more transfer cases. Li *et al* [8] uses the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm in optimizing the multi-objective function of ATC. The power transfer for two transfer cases is obtained simultaneously by using the BFGS whilst considering the power flow and small-signal stability limitations as the constraint of optimization process.

In a daily operation of deregulated power system, several active power sources are increased at two or more selling areas in order to transfer the power to a buying area without jeopardizing the system security. This paper presents the Pareto based evolutionary programming (EP) technique that used in a simultaneous determination of power transfer (ATC) for two transfer cases. The ATC of two transfer cases are considered as the multi-objective function of EP technique and the power flow limitation is considered as the constraint or fitness of EP. The robustness of Pareto based EP technique in determining the ATCs are verified based on a case study of IEEE 24 bus system. The ATCs are obtained referring to the bilateral power transfer from selling areas 1 and 2 to a buying area 3 and also from selling areas 1 and 3 to a buying area 2.

II. MULTI-OBJECTIVE FUNCTION OF ATC USING PARETO CONCEPT

In many practical problems, several optimization criteria need to be estimated simultaneously and it is often not advisable to combine them to become a single objective. Multi-objective optimization is basically referring to the concept of Pareto-optimality [9] and the solution is said to be a Pareto-optimal front if the variations of one objective function can improve the other objective function. In Fig. 1, F1 and F2 are two different directions of ATC objective function. The solutions marked with triangle are called as non-dominated solutions and these functions are laid in plane with the Pareto-optimal front. The best optimized ATC values (located at F1 and F2) are obtained based on the non-dominated solutions or Pareto-optimal front. On the other hand, the solutions marked with circle are said to be dominated solutions or non Pareto-optimal front. The dominated solutions or non Pareto-optimal front does not provide best optimized value of ATCs.

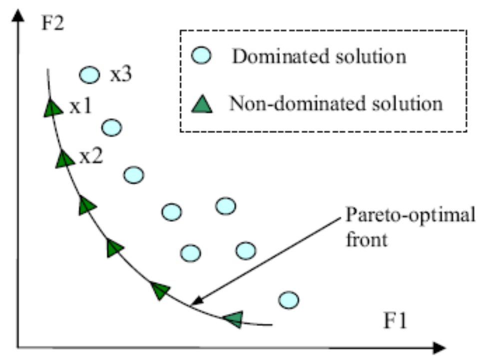

Fig.1. Non-dominated and dominated solutions for the estimation of ATC multi-objective function

Particularly, the Pareto-optimal front solution or non-dominated solution is referred to as the solution x is not dominated by any other feasible solutions x. If the domination operator is "$\succ$", therefore the x can be defined as,

a) $x_1 \succ x_3$ and $x_2 \succ x_3$ (x_3 is dominated).
b) $x_1 \succ x_2$ and $x_2 \succ x_1$ (x_1, x_2 are non-dominated). In this case, the improvement of F1 is only possible by accepting a degradation of F2 and vice-versa.

III. EVOLUTIONARY PROGRAMMING TECHNIQUE

Evolutionary Programming seeks the optimal solution by evolving a population of candidates over several generations or iterations [10]. In each iteration, a new population is obtained from an existing population through the use of mutation operator. A degree of optimality for each candidate or individual is measured by their fitness. In a competition scheme of EP, the individuals of a population undergo competition process to identify the winning candidates or offspring for the next generation. Then, the EP procedure is repeated until the population evolves towards the global optimal point. The EP process is terminated when the difference between maximum fitness and minimum fitness is less than a specified value and then the optimum objective function is obtained.

IV. EP IN THE ATC DETERMINATIONS

In this section, the theory of EP with the modified Gaussian technique is first described, and then followed by the description of ATC determinations using EP technique.

A. *EP Algorithm with the Modified Gaussian Formulation*

In the EP algorithm, the modified Gaussian formulation is a new mutation technique that used to improve the capability of global maximum search of a new population [11]. The technique is suitable for cases that consist of large differences in size between individuals. In the new mutation technique, the first order sensitivity function is utilized in estimating linear changes of offspring with respect to the modified Gaussian variables. The process involved in EP that used to determine the multi-objective function of ATC is described as follows:

a) Establish a solved base case power flow solution.

b) Specify the area of transfers. The area-to-area transfer considers participation of all generators in the specified selling areas and all loads in the specified buying areas. In this case, two or more areas are assigned as the selling areas.

c) The individuals of an initial population are determined by generating a uniform distribution of random variables. Each individual in a population, x_{par_m}, represents as an additional amount of MW capacity specified only for one generating unit. In a case where there are numerous generating units in two or more selling areas, therefore the individuals of all populations are specified as $x_{par_{mn}}$. Where, m is 1, 2, 3,….,*pop*, n is the number of generating units of all the selling areas and *pop* is the population size.

d) Determine the additional amount of loads at the buying area by using (1).

$$newPload_{lm} = Pload_l + \frac{Pload_l}{\sum_{l=1}^{Nload} Pload_l} \times \sum_{n=1}^{Ngen} x_{par_{mn}} \tag{1}$$

where,

- $newPload_{lm}$: new amount of load in the buying area in which it is specified based on the additional amount of generation capacity, $x_{par_{mn}}$.
- $Pload_l$: base MW value of each load in a buying area.
- l : 1,2,3,…..,*Nload*.
- *Nload* : total number of load bus in a buying area.
- *Ngen* : total number of generator bus in a selling area.

e) Establish a load flow solution by considering the additional amount of MW capacity for each generating unit, $x_{par_{mn}}$ and a new MW capacity for each load unit, $newPload_{lm}$. This shows that the load flow solution should be performed several times referring to the mth individual. In each load flow solution, determine the fitness value, f_m, which referred to as the minimum difference between limiting line (or line capacity) and the respective MVA power flow. The f_m is obtained referring to the mth individual of $x_{par_{mn}}$.

f) Each parent, $x_{par_{mn}}$, is mutated to a new population or offspring, $x_{off_{mn}}$, by altering the information contained in each individual. The mth individual in the offspring population is obtained by using a new mutation technique which incorporates first order sensitivity and the modified Gaussian formulation and it is given by,

$$x_{off_{mn}} = x_{par_{mn}} + \left[\left(\frac{\partial x_{par_n}}{\partial N(f_m, \mu_n, \sigma_n)} \right) \times \{1 - N(f_m, \mu_n, \sigma_n)\} \right] \quad (2)$$

where,

$\left(\dfrac{\partial x_{par_n}}{\partial N(f_m, \mu_n, \sigma_n)} \right)$: sensitivity of individual x_{par} with respect to its modified Gaussian variable. The sensitivity is obtained corresponding to each population.

$N(f_m, \mu_n, \sigma_n)$ is the modified Gaussian formulation which denotes as $e^{\left(-(f_m - \mu_n)^2 / 2\sigma_n^2\right)}$, where, μ_n is the mean identified as the targeted fitness value of 1MVA. This shows that x_{off} is a suitable value for new additional amount of generation capacity provided that the maximum MVA power flow is less than the limiting line by 1 MVA. σ_n is the standard deviation denotes as the maximum value of fitness, f_{max}. The first order sensitivity is given by,

$$\frac{\partial x_{par_n}}{\partial N(f_m, \mu_n, \sigma_n)} = \frac{\max x_{par_n} - \min x_{par_n}}{\max N(f_m, \mu_n, \sigma_n) - \min N(f_m, \mu_n, \sigma_n)}$$

(3)

where,

max x_{par_n} : maximum value of individual in each population.

min x_{par_n} : minimum value of individual in each population.

The first order sensitivity is used to overcome the impediment of local maxima or local minima, which normally occur for cases with large value of fitness. Hence, the improvements in searching the global maxima or global minima can easily be obtained by using the new mutation technique. The max $N(f_m, \mu_n, \sigma_n)$ and min $N(f_m, \mu_n, \sigma_n)$ are the maximum and minimum values of modified Gaussian variable, respectively.

g) Each offspring population produced by the mutation process is combined with the parent population to undergo a competition process in order to identify candidates for the next generation. Any individuals either from $x_{par_{mn}}$ or $x_{off_{mn}}$ are competent for the next generation if its fitness, f_m, is equal or approximately close to 1MVA. The individuals selected from $x_{par_{mn}}$ and $x_{off_{mn}}$ are defined as x_{mn}. Otherwise, the offspring population, $x_{off_{mn}}$, is chosen for the next generation and it is defined as x_{mn}.

h) The convergence criteria for EP optimization process is achieved when the mismatch between maximum fitness, f_{max} and minimum fitness, f_{min}, is less than or equal to 0.001. Otherwise go to step d) where x_{mn} ascribed as $x_{par_{mn}}$ and the mutation process is repeated.

i) Obtain the ATC value for each selling area which is determined as the sum of additional generation capacities, x_{mn}, of the selling area.

V. TEST RESULTS AND DISCUSSION

A case study of IEEE 24 bus system is used to demonstrate the effectiveness of Pareto based EP technique in estimating the multi-objective function of ATC for transfer case from selling areas 1 and 2 to a buying area 3 and also from selling areas 1 and 3 to a buying area 2. The system is divided into three areas as shown in Fig. 2. In the 24 bus system, area 1 and area 2 are interconnected by tie-lines 21–22, 17–22, 19–20 and 11–14. There are 5 tie-lines connecting between area 3 and area 2 which are lines 3–9, 4–9, 1–5, 2–6 and 7–8, and area 1 and area 3 are interconnected by tie-line 3–24.

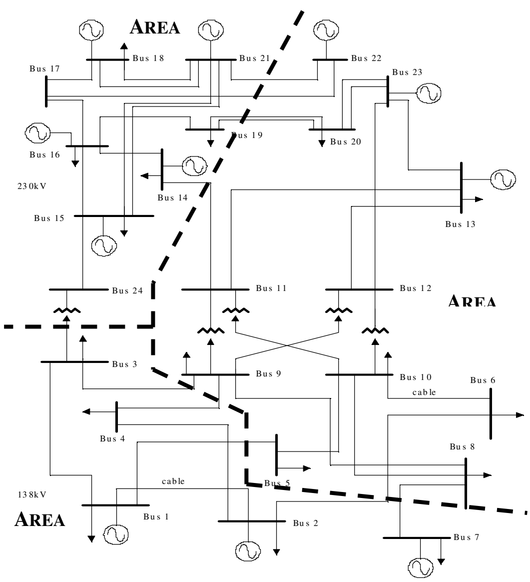

Fig. 2. A single line diagram of IEEE 24 bus system

A. *Results of ATC using Pareto based EP with Modified Gaussian formulation*

The Pareto based EP technique is used to simultaneously determine the optimum ATC for transfer case from selling areas 1 and 2 to a buying area 3. There are 7 populations used in the EP optimization process wherein 5 and 2 populations of additional generation capacities, x_{mn}, are for the selling areas 1 and 2, respectively. Simultaneously, each population consists of 6 individuals of additional generation capacity. The maximum value of ATCs are determined by referring to the maximum value of additional generation capacity, x_{mn}, specified for each generating unit in the selling areas 1 and 2. The maximum value of additional generation capacity for each generating unit in the selling areas 1 and 2 are shown in Table 1. It is obvious that the EP optimization process yields relatively similar value of individuals in each population. Simultaneously, the fitness for each individual is relatively similar which gives 0.0009 differences between the maximum fitness and minimum fitness. This shows that the maximum value of additional generation capacities are obtained based on the difference between maximum fitness and minimum fitness that is less than the specified stopping criteria of EP optimization process which is 0.001. The fitness for each individual is obtained based on the limiting line from bus 3 to bus 24.

The maximum value of additional generation capacities for each area given in Table 1 are used to determine the maximum value of ATC for the transfer case from selling areas 1 and 2 to a buying area 3. In each individual, the sum of maximum additional generation capacities for selling areas 1 and 2 gives the maximum ATC value for transfer cases from selling area 1 to buying area 3 and from selling area 2 to buying area 3, respectively and this is shown in Table II.

In Table III, the maximum value of ATC for each transfer case is obtained by referring to the average value of maximum ATC given in Table 2. The maximum value of ATC from selling area 1 to buying area 3 is 392.59 MW and the maximum value of ATC from selling area 2 to buying area 3 is 146.77 MW. Table 3 shows that selling area 1 has the capability in transferring large amount of power compared to selling area 2. This is due to the fact that selling area 1 consists of many generating units as compared to the selling area 2.

TABLE 1

THE MAXIMUM ADDITIONAL GENERATION CAPACIRIES

FOR THE SELLING AREAS 1 AND 2

Number of Individual, m	Optimum value of additional generation capacities, x_{mn} (MW)							Limiting Line		Line Rating (MVA)	Power Flow (MVA)	Fitness (Line Rating-Power Flow)	Total CPU Time (sec)
	Generating Units in Selling Area 1					Generating Units in Selling Area 2							
	Gen. 14	Gen. 15	Gen. 16	Gen. 18	Gen. 21	Gen. 22	Gen. 23	From bus	To bus				
1	99.51	62.12	86.91	113.91	29.89	28.91	117.89	3	24	400	398.8192	1.1808	45.6
2	97.81	62.16	86.88	114.28	30.25	31.49	115.47	3	24	400	398.8193	1.1807	
3	99.54	63.09	87.14	113.05	30.04	29.52	116.41	3	24	400	398.8194	1.1806	
4	99.56	63.94	87.33	112.31	30.17	30.05	115.13	3	24	400	398.8196	1.1804	
5	96.64	60.08	86.36	116.39	30.17	31.86	117.09	3	24	400	398.8194	1.1806	
6	99.51	62.12	86.91	113.91	29.89	28.91	117.89	3	24	400	398.8201	1.1799	

TABLE II

MAXIMUM ATC VALUE OF EACH INDIVIDUAL FOR TRANSFER CASES FROM SELLING AREAS 1 AND 2 TO A BUYING AREA 3

Number of Individual	Transfer Case			
	From Selling Area 1	To Buying Area 3	From Selling Area 2	To Buying Area 3
	ATC (MW)		ATC (MW)	
1	392.34		146.80	
2	391.39		146.96	
3	392.86		145.93	
4	393.31		145.18	
5	393.31		148.95	
6	392.34		146.80	

TABLE III

ACTUAL MAXIMUM ATC VALUE FOR TRANSFER CASES FROM SELLING AREAS 1 AND 2 TO A BUYING AREA 3

Transfer case		ATC (MW)
From Selling Area	To Buying Area	
1	3	392.59
2	3	146.77

On the other hand, the maximum value of ATC for the transfer case from selling areas 1 and 3 to a buying area 2 are shown in Table IV. In Table IV, the transfer cases from selling area 1 to buying area 2 and from selling area 3 to buying area 2 yields the maximum ATC value of 173.75 MW and 174.77 MW, respectively. This shows that both of the selling areas 1 and 3 have the potential in providing relatively similar amount of maximum power transfers.

TABLE IV

ACTUAL MAXIMUM ATC VALUE FOR TRANSFER CASES FROM SELLING AREAS 1 AND 3 TO A BUYING AREA 2

Transfer case		ATC (MW)
From Selling Area	To Buying Area	
1	2	173.75
3	2	174.77

Different optimized ATC value is obtained at every run of EP optimization process and this can be described in terms of Pareto-optimal front considering two objective functions (generally called as multi-objective function) of ATC shown in Fig. 3 and Fig 4. In Fig. 3, axis x is a plane for ATC with the transfer case from selling area 1 to buying area 3 and axis y is a plane for ATC with the transfer case from selling area 2 to buying area 3. ATC that is increased at a particular selling area will decrease the ATC at other selling area and vice-versa. The best optimum value of ATCs for the two transfer cases are obtained based on the Pareto-optimal front or non-dominated solutions. In Fig. 3, the maximum value of ATC for transfer case from selling area 1 to buying area 3 is 392.59 MW and this gives the minimum ATC value of 18.42 MW for transfer case from selling area 2 to buying area 3. On the other hand, the maximum ATC value for transfer case from selling area 2 to buying area 3 is 146.77 MW and this gives the minimum ATC value of 88.88 MW for transfer case from selling area 1 to buying area 3. This shows that the maximum value of ATC for transfer cases from area 1 to area 3 is 392.59 MW and from area 2 to area 3 is 146.77 MW. The two maximum values of ATC are located in the plane of Pareto optimal front as shown in Fig. 3. In the Pareto-optimal front or non-dominated solution, the maximum value of ATCs have less potential in violating the system security compared to the extensive amount of ATCs that are obtained based on the non Pareto-optimal front or dominated solutions. The non Pareto-optimal front or dominated solution does not provide best optimum value of ATCs. In the dominated solution, extensive ATC amount of 429.35 MW is obtained for the transfer case from selling area 1 to buying area 3 and the transfer case from selling area 2 to buying area 3 provides extensive amount of ATC which is 155.92 MW. The extensive amounts of ATC agitate to a high potential in power system security violation such as an overloaded power flow in a transmission line.

Fig. 4 represents the best optimum value of ATCs for the transfer cases from selling areas 1 and 3 to a buying area 2. These transfer cases are obtained based on the Pareto-optimal front or non-dominated solutions. In Fig. 4, the maximum ATC value for the transfer case from selling area 1 to buying area 2 is 173.75 MW and this yields to the minimum ATC value of 71.75 MW for the transfer case from selling area 3 to buying area 2. On the other hand, the maximum value of ATC for the transfer case from selling area 3 to buying area 2 is 174.77 MW and this reduces the ATC value to 112.35 MW for the transfer case from selling area 1 to buying area 2. This illustrates that the maximum value of ATC for the transfer cases from area 1 to area 2 is 173.75 MW and from area 3 to area 2 is 174.77 MW. The two maximum values of ATC are located in the plane of Pareto optimal front as shown in Fig. 4. In the Pareto-optimal front or non-dominated solution, the maximum value of ATCs have less potential in violating the system security compared to the extensive amount of ATCs that are obtained based on the non Pareto-optimal front or dominated solutions. The non Pareto-optimal front or dominated solution is not able to provide best optimum value of ATCs. In the dominated solution, the transfer case from selling area 3 to buying area 2 provides extensive amount of ATC which is 181.34 MW and the extensive ATC amount of 178.21 MW is obtained for the transfer case from selling area 1 to buying area 2. Hence, the violation of power system security may occur due to the extensive amount of ATC. The optimization process considering the Pareto-optimal front plays an important role in the assessment of ATC multi-objective function in which this may assist the electric utility to accurately estimate the ATCs whilst concerning on the power system security.

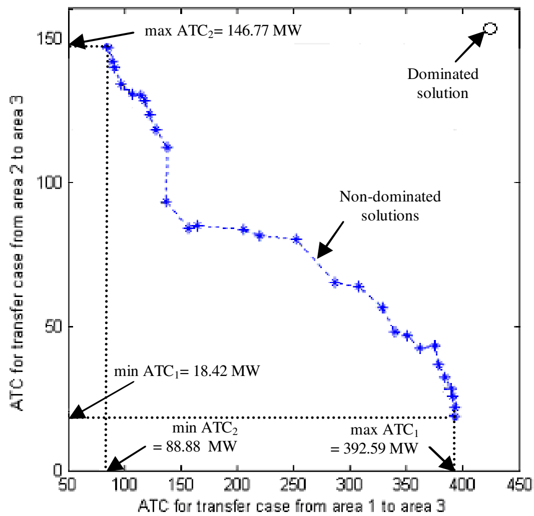

Fig.3. Non-dominated and dominated solutions of ATCs for the transfer cases from selling areas 1 and 3 to a buying area 2

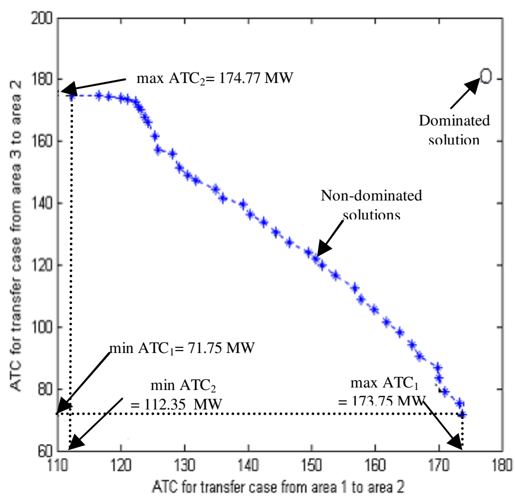

Fig.4. Non-dominated and dominated solutions of ATCs for the transfer cases from selling areas 1 and 2 to a buying area 3

VI. CONCLUSION

This paper has presented the assessment of simultaneous ATC determination for two transfer cases using the Pareto based EP technique. Robustness of the technique in ATC determinations is validated on a case study of IEEE 24 bus system. Simultaneous determination of ATC for two transfer cases are considered as the multi-objective function of Pareto based EP technique and the power transfer involved is the transfer cases from selling areas 1 and 2 to a buying area 3 and also from selling areas 1 and 3 to a buying area 2. The concept of Pareto is comprised of two important factors which are the non-dominated and dominated solutions. The non-dominated solution or Pareto-optimal front provides the best optimum value of ATC for the two transfer cases. On the other hand, dominated solution or non Pareto-optimal front gives extensive optimum amount of ATC for the two transfer cases and this may yield to a high potential of power system security violation. Therefore, simultaneous ATC determination for two or more transfer cases should be performed by considering the Pareto-optimal front solution in order to ensure that there is less potential in violating the power system security.

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