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# Available Transfer Capability Optimisation Using Evolutionary Programming

**Muhammad Murtadha Othman[1] & Bibi Norashiqin Sheikh Rahimullah**

*Faculty of Electrical Engineering*
*Universiti Teknologi MARA (UiTM), Malaysia*
*[1]Email: m_murtadha@salam.uitm.edu.my*

## ABSTRACT

*In a deregulated electric power industry, transmission providers are required to rapidly produce commercially viable information of available transfer capability (ATC) so that such information can help power marketers, sellers and buyers in planning, operation and reserving transmission services. ATC is a measure of the additional amount of power transfer that may flow across the interface, over and above the base case flows without jeopardizing power system security. This paper presents the ATC determination using the evolutionary programming (EP) technique using modified Gaussian formulation. The proposed EP technique has the ability in providing accurate ATC results and the computation burden caused by the AC power flow solutions are significantly reduced. The outages of critical line that adversely affect the amount of ATC are determined by performing the line contingency ranking and selection. ATC determinations have been made on the case study of Malaysian system. Comparison in terms of accuracy and computation time in estimating the ATC are made by considering the three methods which are the EP using modified Gaussian formulation (EPMG), EP using standard Gaussian formulation (EPSG) and the recursive AC power flow solution (RACPF).*

## Introduction

With the recent trend towards deregulating power systems around the world, transfer capability computation has become one of the key issues

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for all companies participating in the power transaction activities. Due to open transmission access, electric utilities are required to produce commercially viable information of the 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]. ATC can also become a useful indicator for the operator to indicate the amount by which the inter area power transfers can be increased without compromising system security. An overly conservative estimate of transfer capability can lead to over subscription of transmission services and inefficient use of the network. In the context of transfer capability, TTC is defined 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 [2]. On the other hand, ATC is defined as 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].

Assessing the ATC for a practical power system using these analytical methods is a computationally demanding task especially when numerous operating conditions and contingencies have to be considered. There are various analytical methods prevalent to determine ATC in which these methods use the DC power flow [1], sensitivity [4], recursive AC power flow [5], optimal power flow [6] and quadratic sensitivity [7]. The recursive AC power flow (RACPF) method gives an accurate solution in determining the ATC because it considers the effects of reactive power flows and voltage limits. However, transfer capability evaluation using RAPF is time-consuming because it requires a load flow solution at every transfer step size. To avoid many recursive AC power flow solutions, optimal power flow techniques are used. In the ATC determinations, various optimal power flow techniques have been used in which it is based on the genetic algorithm, sequential quadratic programming, linear programming and evolutionary programming (EP) [8]. In recent years, enormous progress has been achieved in the application of EP technique to power system problems such as unit commitment, security assessment and economic dispatch [9].

This paper presents a new computationally accurate method for evaluating ATC based on the EP technique using modified Gaussian formulation (EPMG). The EP performance is improved by using the modified Gaussian formulation in which it has the capability of providing a new population in a fast global maximum domain search. Hence, the other advantage of using the EPMG is that it has the ability to reduce the time consuming AC power flow computations in the ATC determination. Prior to the ATC evaluation, contingency ranking and selection techniques are used to define the critical lines in a system that can adversely affect the transfer capability assessment. The effectiveness of EPMG is verified by illustrating the results of ATC for the Malaysian system. ATC results obtained from the EPMG prove that the method is satisfactorily accurate and it is faster than the ATC methods using the EP with standard Gaussian formulation (EPSG) and the RACPF.

## Methodology

The transfer capability of the system is analyzed under two different sets of transfer, which are area-to-area ATC and point-to-point ATC. Area-to-area ATC is the additional amount of power transferred from the selling area to the buying area. On the other hand, point-to-point ATC is the additional amount of power transferred from the selling bus to the buying bus. The ATCs are quantified by considering the effect of contingency such as line outage. Considering outages of all lines for a large-scale interconnected power system is impractical and therefore, contingency ranking is used to select the critical lines that may adversely affect the ATC during outages.

In this section, the theory of EPMG is first described, and then followed by the descriptions of EPSG and the procedure that used to determine ATCs using EPs and RACPF are explained.

### EP using Modified Gaussian Formulation

EP is an artificial intelligent method with a stochastic optimization algorithm which emphasizes on the behavioural linkage between parents and their offsprings that can give solutions to complex nonlinear problems. Fitness evaluations in EP highlight the behavior of individuals which propagate its features to new generations. The process in EP involves three steps, namely, mutation, competition and natural selection [9]. In general, the initial population of ATC is generated randomly within the feasible range of 0 MW and 1000 MW, and then the fitness is determined for each individual of initial population. The fitness can be obtained from the maximum difference between voltage magnitude and the respective voltage magnitude limits, and also between the MVA power flow and respective thermal limit. Then, a new population or offspring is obtained from the initial population which undergoes through the mutation process and the fitness for each new individual is determined. The combination of first order sensitivity and the modified Gaussian formulation is a new mutation technique that used in EP in order to improve the capability of global maximum search for a new population. In the new mutation technique, the first order sensitivity function is used to determine the linear changes of offspring with respect to its modified Gaussian variables. The proposed mutation technique is suitable for cases which consist of large differences in size between individuals fitness. In the competition stage, the individuals with fitness below the specified level are selected from the two populations by using the natural selection mechanism. The explained EP procedure is repeated until the mismatch between the maximum individual and minimum individual is less than 0.1.

For the transfer case between the selling area and buying area (or between the selling bus and buying bus), ATC is specified as the objective function of EP techniques. Generally, the EP technique simultaneously increases both the total generation, $PG_{total}$ and the total load, $PD_{total}$ until the fitness reaches to 0.1. ATC is then determined from the optimized $PG_{total}$ less the base case $PG_{total}$. The modified Gaussian formulation based EP (EPMG) procedure that used in the ATC estimation is described as follows:

a. A parent population, $x_{par,m}$ is determined by generating a uniform distribution of random variables. Each individual of the parent population, $x_{par}$, represents as $PG_{total}$ and $PD_{total}$. Then, for all the $x_{par,m}$, the fitness values, $f_m$ are determined by solving the AC power flow solution. The fitness for each individual, $f$ is represented by the maximum difference between voltage magnitude and respective voltage magnitude limits, and also the MVA power flow and respective thermal limit. $m$ is 1, 2, 3,.., *pop*, where *pop* is the population size. The initial process of EP usually does not give the $f_m$ fairly below 0.1. Hence, the following procedures is performed recursively until the $x_{par,m}$ is optimized which gives the $f_m$ fairly below 0.1.
b. The parent is then mutated to a new population or offspring, $x_{off}$ by altering the information contained in each individual. The $m^{th}$ individual in the offspring population which incorporates the first order sensitivity in the mutation process is given as,

$$x_{off,m} = x_{par,m} + \left( \left| \frac{\partial x_{par}}{\partial N(f, \mu, \sigma)} \right| \times \left\{ 1 - N(f_m, \mu, \sigma) \right\} \right) \tag{1}$$

where,

$\left|\dfrac{\partial x_{par}}{\partial N(f,\mu,\sigma)}\right|$ : sensitivity of individual $x_{par}$ with respect to its modified Gaussian variable.

$N(f_m,\mu,\sigma)$ : modified Gaussian formulation with respect to $x_{par,m}$, denotes as $e^{\left(\frac{-(f_m-\mu)^2}{2\sigma^2}\right)}$.

$\mu$ : targeted fitness value of 0.1.

$\sigma$ : maximum value of $f_m$.

The first order sensitivity is given in equation (2).

$$\frac{\partial x_{par}}{\partial N(f,\mu,\sigma)} = \frac{\max\ x_{par} - \min\ x_{par}}{\max N(f,\mu,\sigma) - \min\ N(f,\mu,\sigma)} \tag{2}$$

where,

max $x_{par}$ and min $x_{par}$ : maximum and minimum of the individuals, respectively.

Utilizing the first order sensitivity usually prevents the occurrence of local maxima or local minima due to the cases with large values of fitness. The max $N(f, \mu, \sigma)$ and min $N(f, \mu, \sigma)$ are the maximum and minimum of modified Gaussian variables corresponds to $x_{par}$, respectively.

c. The offsprings produced from the mutation process are combined with the parents to undergo a competition process in order to identify the candidates for the next generation. Any individual from the combined population of $x_{off}$ and $x_{par}$ is competent for the next generation if its fitness, $f_m$, is below the specified level of 0.1. Otherwise, the individual $x_{off}$ is chosen for the next generation.

d. The convergence criteria for the EP optimization process is achieved when the individual fitness is fairly below the specified level of 0.1, as well as when the mismatch between the maximum individual, *max* $x$, and the minimum individual, *min* $x$, is less than or equal to 0.1. Otherwise go to step b) and the mutation process is repeated.

The overall process of EPMG is summarized in terms of flowchart as shown in Figure 1.

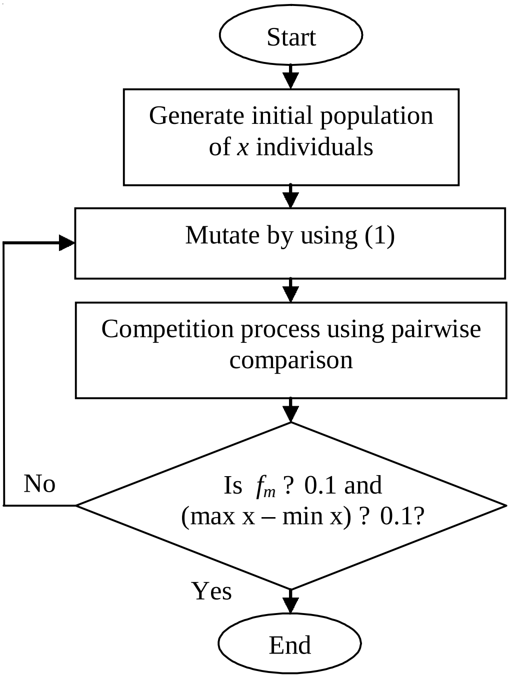

Figure 1: Flowchart of Evolutionary Programming Algorithm

## EP using Standard Gaussian Formulation

The procedure for EP that uses the standard Gaussian mutation technique (EPSG) is similar to the procedure of EPMG except that the modified Gaussian formulation given in equation (1) is replaced by the standard Gaussian formulation. By using the Gaussian formulation in the mutation operator, each $m^{th}$ individual in the parent population is mutated and assigned as $x_{off,\, m}$ [9]. The standard Gaussian formulation used in the mutation operator is incorporated in the $m^{th}$ individual of the offspring population which is given by,

$$x_{off,m} = x_{par,m} + N(\mu, \sigma) \tag{3}$$

where,

$N(\mu, \sigma)$ : standard Gaussian formulation with mean, $\mu$, and standard deviation, $\sigma$.

$\mu$ : assigned with the value of 0.

$$\sigma = \left( \beta \left( \max\ x_{par} - \min\ x_{par} \right) \frac{f_m}{f_{\max}} \right)^{1/2}$$

$\beta$ : mutation scale that has a value in the range of $0 < \beta \leq 1$.

The EP procedure with the standard Gaussian mutation technique is similar to that shown in Figure 1 except that equation (1) is replaced with equation (3).

## ATC Determination Using EPs

In general, the procedure to determine ATC involves the definition of a base case, determination of network response and finding the maximum power transfer or TTC. The contingency ranking and selection techniques are used to define the critical lines in a system that can adversely affect the value of ATC during outage. The following procedure is the ATC evaluation using EPs.

a. Determine critical lines in a system by performing the line contingency ranking and selection [10]. The line loading performance index ($PI_{MW}$) and bus voltage performance index ($PI_V$) are used to rank the line contingencies. These performance indices are ranked and lines with $PI$ values above the base case $PI$ index, $PI_{Base\ Case}$ are considered as critical lines in the system.
b. Establish a solved base case AC power flow solution.
c. Perform line outage simulations by considering one of the critical lines.
d. Specify the areas or points of transfer case. The area-to-area transfer considers participation of all generators in the specified selling area and all loads in the specified buying area. For the point-to-point transfer, a generator is considered as a selling bus and a load is a buying bus.
e. Based on the EP techniques as explained in Subsection 2.1 and 2.2, the $PG_{total}$ at selling area or the selling bus and $PD_{total}$ at buying area or the buying bus are optimized which gives the $f_m$ and ($max\ x$ - $min\ x$) fairly below 0.1.
f. Calculate the ATC that is given by the optimized $PG_{total}$, less the $PG_{total}$ at base case power flow.

At the base case condition, the ATC ($ATC^0$) is obtained without considering steps a and c.

### ATC Estimation using Recursive AC Power Flow Method

The interarea ATC determination using recursive AC power flow (RACPF) method is described in the following procedure:

a. Determine critical lines in a system by performing the line contingency ranking and selection [10]. The line loading performance index ($PI_{MW}$) and bus voltage performance index ($PI_V$) are used to rank the line contingencies. These performance indices are ranked and lines with *PI* values above the base case *PI* index, $PI_{Base\ Case}$ are considered as critical lines in the system.
b. Establish a solved base case AC power flow solution.
c. Perform line outage simulation by considering one of the critical lines.
d. Specify the areas or points of transfer case.
e. Increase at equal incremental MW steps for all the generators at selling area and also all the loads at buying area. For the point-to-point transfer case, the generator at selling bus and the load at buying bus is increased at equal incremental steps. The power transfer is increased until the limitations of voltage magnitude or the MVA power flow is violated.
f. Calculate the ATC that is given by the maximum power transfer at the limiting case, less the base case power flow.

At the base case condition, the ATC ($ATC^0$) is obtained without considering steps a) and c).

## Discussion of Research Findings

The performance of the EP techniques in the ATC determination is verified in terms of accuracy and speed. CPU timing for the transfer capability analysis was obtained using 2 GHz Pentium 4 with 320 MB of memory. The Malaysian power system is used as a test system to illustrate the robustness of the EPs and the RACPF in determining the ATC. The system is a simplified 241-bus system with five areas, namely, area 1 (North), area 2 (East), area 3 (Central), area 4 (South) and area 5 (PUB), as shown in Figure 2. The lower voltage limit of 0.9 p.u., the upper voltage limit of 1.1 p.u. and the limitation of MVA power flow are considered in the transfer capability analysis.

Prior to the ATC calculation, contingency ranking is performed on the 368 lines in the system in which after contingency selection, 44 lines

Figure 2: The Malaysian System

have been identified as critical lines. In this analysis, two critical lines connected from bus 1468 to bus 2468 and from bus 2308 to bus 2608 are selected randomly and it is considered as the line outage for the interarea and point-to-point ATCs determination.

Comparisons in terms of ATC results and the computational time are made between the EPMG, EPSG and RACPF. The results of area-to-area ATC and point-to-point ATC are shown in Table 1 and Table 2, respectively.

In Tables 1 and 2, all the ATCs are obtained due to the line limitation which constraints the increase of power transfer. For instance in Table 1, by considering the line outage of 1468-2468, the overloaded line 1570-9222 limits the increase of power transfer which gives the ATC value of 123 MW for the interarea transfer case from area 1 to area 2. This is similar to the point-to-point ATC results as shown in Table 2. Whereby, for the transfer case from bus 9020 to bus 3636 considering line outage 1468-2468, the overloaded line 1182-9020 restraints the increase of power transfer that yields to the ATC result of 80 MW. Hence, these show that the point-to-point ATC and area-to-area ATC are obtained not due to the voltage violations.

Tables 1 and 2 shows that the ATC results determined by the EPMG and EPSG are in a very close agreement compared to the ATC result determined by RACPF. This shows that the EPMG and EPSG provide much more accurate ATC results compared to the RACPF. This is due to the fact that the fitness for the EP techniques is fairly below 0.1. The fitness considered in the EP techniques is the mismatch between system operation and the respective system operating limit. On the other hand, the mismatch between system operation and the respective system operating limit provided by RACPF is larger than 0.1. In terms of computational time, it is noted that the ATC computations using EPMG is much faster as compared to the EPSG and RACPF. This is because that the EPMG simulate less number of load flow solution in the ATC determination. From the ATC results shown in Table 1 and Table 2, it is observed that the proposed EP method is able to provide accurate ATC result with fairly short computation time.

Table 1: Results of Area-to-Area ATC

| Area of Transfers | | | ATC (MW) | | | CPU Time (seconds) | | |
|---|---|---|---|---|---|---|---|---|
| Selling Area | Buying Area | Limiting Line | EPMG | EPSG | RACPF | EPMG | EPSG | RACPF |
| 1 | 2 | 1570-9222 | 121.4 | 121.6 | 123 | 10.19 | 20.39 | 35.68 |
| 2 | 3 | 2394-9092 | 382.7 | 382.1 | 384 | 29.41 | 58.82 | 102.94 |
| 3 | 4 | 2436-9162 | 256.1 | 256.5 | 258 | 18.57 | 37.14 | 65 |
| 4 | 5 | 1424-9140 | 238.2 | 238.7 | 240 | 16.67 | 33.34 | 58.34 |
| 2 | 1 | 2394-9092 | 381.2 | 381.1 | 383 | 26.91 | 53.83 | 94.2 |
| 3 | 2 | 2436-9162 | 267.6 | 267.4 | 269 | 19.82 | 39.65 | 69.38 |
| 4 | 3 | 1424-9140 | 246.8 | 246.7 | 248 | 18.78 | 37.56 | 65.73 |
| 5 | 4 | 1636-2636 | 314.8 | 314.1 | 316 | 22.38 | 44.75 | 78.32 |
| 2 | 4 | 1636-2636 | 314.2 | 314.6 | 316 | 22.12 | 44.24 | 77.42 |
| 1 | 3 | 1570-9222 | 121.1 | 121.3 | 123 | 8.76 | 17.51 | 30.65 |
| 2 | 5 | 2394-9092 | 383.3 | 383.8 | 385 | 27.69 | 55.39 | 96.93 |
| 4 | 2 | 1424-9140 | 248.4 | 248.5 | 250 | 16.43 | 32.86 | 57.51 |
| 5 | 3 | 2438-5438 | 499.1 | 499.9 | 501 | 34.46 | 68.91 | 120.6 |
| 3 | 1 | 2436-9162 | 254.7 | 254.3 | 256 | 18.05 | 36.10 | 63.18 |
| 5 | 2 | 2438-5438 | 500.9 | 500.4 | 502 | 37.31 | 74.62 | 130.58 |
| 3 | 5 | 2436-9162 | 259.9 | 259.1 | 261 | 18.61 | 37.22 | 65.14 |
| 4 | 1 | 1424-9140 | 247.6 | 247.9 | 249 | 18. | 36.01 | 63.01 |
| 1 | 4 | 1570-9222 | 121.2 | 121.8 | 123 | 9.66 | 19.33 | 33.82 |
| 5 | 1 | 90000-99001 | 500.5 | 500.9 | 502 | 37 | 74 | 129.5 |

Table 2: Results of Point-to-Point ATC

| Point of Transfers | | Limiting Line | ATC (MW) | | | CPU Times (seconds) | | |
|---|---|---|---|---|---|---|---|---|
| Selling Bus | Buying Bus | | EPMG | EPSG | RACPF | EPMG | EPSG | RACPF |
| 9020 | 3636 | 1182-9020 | 78.3 | 78.8 | 80 | 5.87 | 11.75 | 20.56 |
| 9181 | 1250 | 1250-2250 | 115.5 | 115.1 | 117 | 7.87 | 15.75 | 27.56 |
| 9060 | 1468 | 2308-9060 | 30.1 | 30.8 | 32 | 2.49 | 4.97 | 8.7 |
| 9210 | 2420 | 1552-9210 | 36.6 | 36.3 | 38 | 2.91 | 5.83 | 10.2 |
| 9010 | 90000 | 2158-9010 | 18.2 | 18.9 | 20 | 1.62 | 3.23 | 5.658 |
| 99007 | 2602 | 90000-99007 | 148.7 | 148.3 | 150 | 10.30 | 20.61 | 36.06 |
| 9182 | 2250 | 2602-9252 | 255.3 | 255.7 | 257 | 18.47 | 36.95 | 64.66 |
| 9062 | 3341 | 2308-9062 | 30.4 | 30.8 | 32 | 2.51 | 5.02 | 8.78 |
| 9024 | 2494 | 2182-9024 | 72.9 | 72.2 | 74 | 5.38 | 10.75 | 18.82 |
| 99015 | 1326 | 90000-99015 | 34.1 | 34.9 | 34 | 2.69 | 5.38 | 9.41 |
| 9270 | 2414 | 2424-9270 | 38.5 | 38.2 | 40 | 2.70 | 5.41 | 9.46 |
| 9132 | 2908 | 2602-9252 | 250.2 | 250.6 | 252 | 17.91 | 35.81 | 62.67 |
| 9163 | 5438 | 2436-9163 | 21.3 | 21.6 | 23 | 1.62 | 3.24 | 5.67 |
| 9191 | 90000 | 2510-9191 | 44.2 | 44.9 | 45 | 3.46 | 6.91 | 12.1 |
| 99023 | 2722 | 90000-99023 | 148.1 | 148.6 | 150 | 10.58 | 21.16 | 37.03 |
| 9272 | 2638 | 2424-9272 | 38.9 | 38.2 | 40 | 3.07 | 6.15 | 10.76 |
| 9284 | 1182 | 2602-9252 | 21.1 | 21.7 | 253 | 18.19 | 36.38 | 63.67 |
| 9245 | 1424 | 2588-9245 | 18.5 | 18.8 | 20 | 1.68 | 3.36 | 5.88 |
| 9261 | 90000 | 2602-9252 | 245.5 | 245.3 | 247 | 16.02 | 32.04 | 56.07 |

## Conclusion

A new approach for evaluating area-to-area and point-to-point ATCs are presented which uses the evolutionary programming with modified Gaussian formulation (EPMG). The EPMG is used so as to reduce the computation time in determining accurate ATC value. Prior to the contingency ranking and selection method, 44 lines have been identified as critical which may adversely affect the ATC value during outage. The simulation results of ATC prove that the EPMG reduces the computation burden compared to the evolutionary programming using standard Gaussian formulation (EPSG) and the recursive AC power flow solution (RACPF). In terms of accuracy, the EPMG and EPSG provide much more accurate ATC results compared to the RACPF. The proposed technique is especially useful for use in the deregulated electricity market in which the ATCs are required to be posted as a real time market signal so that all transmission users have the same chance to access transmission information.

## Recommendations for Future Research

There is growing concern on the impact of deregulated of electric power industry. Security margins considering power system reliability is well suited to be considered in the transfer capability assessment. Transmission reliable margin (TRM) and capacity benefit margin (CBM) are the two security margins recommended to be considered in the ATC determination. By taking into account the TRM in the transfer capability assessment, the power system is operating in a reliable manner as the uncertainty occurs during the power transfer. On the other hand, CBM is utilized by the load serving entities only during the occurrence of emergency generation deficiencies that may disrupt the power transfer.

There are various implementations of new concepts and ideas to improve ATC. The flexible AC transmission systems (FACTS) devices are recommended to be used at the transmission system so as to improve the ATC value. Thyristor controlled series capacitors (TCSC), static VAR compensator (SVC) and unified power flow controller (UPFC) are the FACTS devices that should be considered to improve the ATC value. On the other hand, the implementation of artificial neural network (ANN) is recommended so that fast and accurate ATC value can be obtained. Implementing the ANN is also to facilitate the system operator works in order to prevent blackouts or power overload that may occur during power transfer.

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