Computing and Analysis of Transfer Capability in Different Scenarios for Khorasan Transmission Network Using Genetic Algorithm

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Abstract
A key concept in restructuring of power industry is Available Transfer Capability (ATC). In several decision making problems and from different viewpoints, the ATC plays an important role and should be computed. In this paper the ATC is determined and analyzed from the planning aspect. The problem is formulated for a regional power system, namely Khorasan province transmission network. Computing of ATC through a specified path which determined in the network formulated as an optimization problem. The aim is to maximize amount of transferable power through the specified path subject to the load flow equations and transmission constraints. Regarding to geographical position of the province, the model is generalized to consider simultaneous transfer capability. Using a probabilistic model, effects of single contingencies on the ATC will be discussed. The Genetic Algorithm as a powerful optimizer is used for solving the problem. Analysis of results shows the proposed method is practical and it would help system planner in the expansion planning process.

1. INTRODUCTION
Electric utility industries of many countries are undergoing a fundamental transformation from regulated and monopolistic to deregulated and competitive industry. In the deregulated environment, transmission lines have a new role and link neighboring power markets. High capacity transmission lines provide the potential of more energy exchange or power transit among the markets. Due to competition in the market, the transmission lines of the network are operated close to their maximum capacities. The maximum capacity of a transmission line is computed based on its thermal capacity and also system constraints such as system stability. A key concept in restructuring of power industry is Available Transfer Capability (ATC). The ATC is the measure of the ability of interconnected electric
systems to reliably move or transfer power from one area to another over all transmission lines or paths between those areas under specified system conditions. It depends also on a number of factors such as the generation dispatch, the system load level and power transfer between areas.

In the deregulated environment, the ATC is one of the most important information for different market players. In several decision making problems, like bidding problem for supplier or demander, and from different aspects such as operation and planning, the ATC can be used as an important index. Furthermore, with computation of the ATC in different directions of the transmission network, useful information regarding optimal network expansion planning can be obtained. Therefore, network planner is able to answer to the basic question of planning, where to build a new transmission line to increase the ATC.

To answer several research questions in the context of ATC, much research has been done in the recent years. Parts of research works are on system reliability and effects of power shipment on it [2, 3]. Other parts are about power flow formulation including transit of power through the network [4]. Calculation of transferable power between areas and analysis of wheeling cost and designing a proper contract are other fields of research [5-8]. However, an important problem is computation of ATC in a specified path [9, 10].

In this paper the ATC is determined and analyzed from the planning aspect. The problem is formulated for a regional power system, namely Khorasan transmission network. The province of Khorasan in north east of Iran has this potential to exchange power with the neighboring countries and the neighboring Iranian power utility industries. Fig.1 shows this capability. To evaluate capabilities of the existing transmission network, computing of the ATC through a path or between two arbitrary nodes is formulated in form of an optimization problem. The aim of this optimization problem is to maximize amount of transferable power through the specified path subject to load flow equations and the transmission constraints. It is assumed that the load level and the generation dispatch are fixed. The model is developed to evaluate effects of single contingencies on the ATC. In this case the objective function is defined as expected value of transferable power and computed using realistic parameters for probabilities of the system contingencies.

Regarding to geographical position of the province, the above model is generalized to solve the problem when multiple paths are considered simultaneously, i.e. simultaneous transfer capability. This model can be applied properly in operation of a competitive power market where bilateral transactions should be evaluated by system operator.

Nowadays, Genetic Algorithms (GAs) are used as powerful tools in solving optimization problems. Among the most important characteristics of these algorithms are their flexibility in handling complex constraints, parallel search in complicated spaces and their compatibility with non-continuous and nonlinear objective functions. These characteristics cause GA to be a powerful tool in solving the operational problems in power systems.

In this paper, Genetic Algorithm is designed to solve the proposed problem for different deterministic and probabilistic models in Khorasan province. Analysis of
results show the proposed method is suitable and it would help system planner in the process of expansion planning taking into account power exchange with the neighboring countries.

2. PROBLEM FORMULATION

To formulate the problem, we consider a transmission network (Fig.2). According to the geographical position, the network has different possibilities for power transmission through the network. It’s clear that power transit through network affects on the network security. Furthermore, it is necessary to calculate allowable transfer capability through different paths. Herein various indexes are such as Total Transmission Capacity (TTC), Transmission Reliability Margin (TRM) and the ATC identified to analyze performance of the transmission network with power transfer capability [11, 12].

![Figure 2: interface transmission network](image)

According to the essence of the transit problem and regarding to the transmission planning viewpoint, generally assume that the results of DC load flow are sufficiently accurate. If we have voltage problems because of special situation of the network, this assumption is not valid and we should use more precise model of the load flow. In the problem formulating to consider transit between two specified buses, it is assumed this amount of power generated in the first bus and consumed at the second bus. To achieve maximum amount of simultaneous transfer capability in specified paths of transmission network, we will meet to an optimization problem:

\[
\text{Maximize } \sum_{i=1}^{N} P_{\text{trans}}(i) \\
\text{Subject to: } P = B \theta \\
- F_j \leq P_j \leq F_j \quad j = 1, ..., NLI, j \neq L
\]  

where \( N \) is the number of paths that are taken into account simultaneously, \( P_{\text{trans}}(i) \) is amount of power that can be transferred between two specific buses of the network, \( P_j \) is transfer power flow on line \( j \), \( F_j \) is capacity of line \( j \), \( NLI \) is the number of lines in the network, \( P \) is vector of injecting power including transferred power through the network, \( B \) is the admittance matrix of the network and \( \theta \) is the vector of voltage angles of the buses. The value of parameter \( F_j \) is selected so that the constraints related to the reliable operation of the network are satisfied.

In the above formulation of the problem, it is assumed weights of the paths in objective function are equal. After solution of optimization problem, maximum transferable power through the specified paths can be calculated. For more precise of model network contingencies should be considered. The occurrence probability of each single contingency can be estimated from the historical data. In this case, the mathematic model will be as follow:

\[
\text{Minimize } \sum_{i=1}^{N} P_{\text{trans}}(i) \\
\text{Subject to: } \begin{align*}
 P_i &= B_i \theta_i \\
 - F_i &\leq P_i \leq F_i & k = 1, ..., NLI \\
 P_s &= B_s \theta_s & s = 2, ..., NSC \\
 (-F_j \leq P_j \leq F_j)_j & j = 1, ..., NLI, j \neq L
\end{align*}
\]

That \( B_i \), \( P_i \) and \( \theta_i \) are the admittance matrix, the injecting power vector, and voltage angles vector of the network buses respectively corresponding to the structure of the network when \( \text{th} \) contingency is occurred, \( NSC \) is the number of important single contingencies and \( L \) is set of line
numbers and each number is corresponding to an important contingency. After solving the optimization problem, maximum transferable power that can be safely exchanged through the network is calculated. It's clear that regarding consideration of contingencies, the solution of this model is very conservative, because the system is almost all of time in normal state. In order to find the proper solution, the deterministic model can be modified and replaced with a probabilistic model.

With assumption that occurrence probabilities of single contingencies are known, the expected value of objective function is considered as decision making criterion. Hence we consider the maximum transferable power as a random variable. Therefore the formulation of problem will be as follow:

\[
\text{Maximize } \sum_{i=1}^{M} \Pr(s) \times J'(s)
\]  

(3)

Where,

\[
J'(s) = \text{Maximize } \sum_{i=1}^{M} P_{\text{trans}}(i,s)
\]

Subject to:

\[
\begin{align*}
& P_i = B_i \theta_j, \quad s = 1, \ldots, \text{NSC} \\
& (-F_j \leq P_j \leq F_j), \quad j = 1, \ldots, \text{NLI}, j \neq I_3
\end{align*}
\]

(4)

\( P_{\text{trans}} (i, s) \) is transit power in the \( i^{th} \) path at \( s^{th} \) structure and \( M \) is number of various structures for the network. The first structure, i.e. \( s=1 \), is corresponding to the structure of normal conditions, when no contingencies are occurred. Also, \( \Pr(s) \) is probability that the network is operated at the structure \( s \) or equivalently is occurrence probability of \( s^{th} \) contingency \((s>2)\). Clearly system is operated more on the first structure, i.e. normal state and therefore, we have:

\[
\Pr(1) \gg \Pr(s) \quad s=2, \ldots, M
\]  

(5)

To compute the maximum transfer capability in problem (3), optimization process in problem (4) should be performed for \( M \) structures.

Thus, the solution of the last model in comparison to the solution of the conservative model (presented in eq.(2)) seems more realistic and therefore useful in the decision making process.

3. GENETIC ALGORITHM (GA)

Genetic Algorithms are an attractive class of computational methods being used for solving a variety of scientific and applied problems such as optimization problems, modeling of complex systems and classification. These algorithms, which are known mostly as powerful tools in optimization, are essentially a mathematical implementation of Darwin's evolution theory. Similarly to Darwin's evolution model, these algorithms use the three operators of inheritance (to transfer the experiences from one generation to the next), coincidence (natural errors that occur in this transfer), and natural choice (those who are more compatible with the environment have a better chance of survival). Their most important characteristic, which separates them from the classical optimization methods, is that they work on a population of solutions to the problem.

Genetic algorithm is essentially a method to generate a new population or generation from a given population. In this process the selection, crossover, and mutation operators are being used. Each member of the population, called a chromosome, is a possible solution for the problem under consideration, and is represented as a (usually binary) chain. Members of each generation are ranked according to a specific criterion called fitness. The choice operator gives those members with a higher fitness ranking a better chance of being present in the next generation. The crossover and mutation operators are applied to each chromosome with a specific probability and cause new chromosomes to be generated in the new generation.

The basic Genetic Algorithm may be
summarized as follows:

**Step 1:** Generate a random initial population with N individuals.

**Step 2:** Calculate the fitness functions of all individuals in the population.

**Step 3:** Select two individual members from the population with probability of selection proportional to their fitness values.

**Step 4:** Apply the crossover and mutation operators to these members with probabilities equal to the crossover rate and mutation rate respectively.

**Step 5:** Repeat steps 3 and 4 until N individuals are generated to form the next generation.

**Step 6:** Go to step 2 and repeat the process until a stopping criteria is met.

To solve an optimization problem using GA, first the possible solutions of the problem have to be coded in chromosomes. Next a fitness function to compare the chromosomes has to be defined. Figure 3 represents the flowchart of Genetic Algorithm performance [13, 14].

![Flowchart of the Genetic Algorithm](image)

**Figure 3: Flowchart of the Genetic Algorithm**

4. PROBLEM SOLUTION USING GA

Calculation of maximum transferable power through different paths that represented in formulation (1), according to the linearity of equality and inequality constraints, is solvable by Linear Programming (LP). However for solving the optimization problems (2) and (3) using LP, problem formulation will be difficult and in some cases for any network structure corresponding to the various contingencies, LP must be run individually. Furthermore if we want to consider more constraints that encompass nonlinearity constraints, such as AC load flow equations, then LP will not be effective and answerable. This is especially difficult if we want to evaluate simultaneous transfer capability in the study network.

Hence in this paper, Genetic Algorithm is selected to solve the optimization problem. One of the important advantages of the GA is its flexibility in modeling of different structures. Based on this flexibility, GA is able to formulate and solve different types of nonlinearity and time variant constraints with discrete or continuous variables for wide range of optimization problems.

Genetic Algorithm that is used for solving of power transit problem can use for solving of problems (2) and (3) by suitable coding and against LP once running is sufficient for it. The results of simultaneous running of algorithm are maximum transfer power in the normal state and circumstances of single contingencies occurrence. In below the way of coding that used in problem (3) are explained.

To variable coding of maximum transfer capability for normal structure 10 bits are considered. So according to the one structure for normal condition and \( M - 1 \) structures corresponding to the \( M - 1 \) probabilistic contingencies, the lengths of chromosomes are equal to \( 10M \) bits.

Assume that the range of transit power is \([0, 500] MW\), then this coding accuracy is suitable and equal to 0.5 \( MW\). After this stage and extraction of chromosomes information, the fitness function corresponding to each chromosome must be identified. Equation (4) represents the general way to calculate fitness of each chromosome for problem (3).

\[
\text{Fitness } (k) = \sum_{s \in S} p_s^r p_{\text{route}} (s) - \beta \sum_{v \in \text{nodes}} \sum_{l=1}^{M} \text{Penalty } (s, l) \tag{6}
\]
where $s$ is set of entire represented structures for the network (including normal condition and structures corresponding to the contingencies), $l$ is set of total lines, $p_l$ is existing probability that system is operated in structure $s$, $\beta$ is weight factor for consideration of penalty function in fitness evaluation. The second term in eq.6 is added to fitness function to penalize unfeasible solution. The value of \textit{Penalty($s$,l)} is correspond to line $l$ when this line is overloaded in the structure $s$. it should be emphasized with increasing the value of line overload, penalty function increases non-linearly.

5. NUMERICAL EXAMPLES

The proposed method in the previous section is applied to compute transfer capability in different directions for Khorasan regional transmission network. Some of important information and Specification of the network is shown in table1.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Number of buses</th>
<th>Number of transformers (400/132 KV)</th>
<th>Number of lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>132 KV</td>
<td>64</td>
<td>5</td>
<td>104</td>
</tr>
<tr>
<td>400 KV</td>
<td>5</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

In application of the proposed method, we consider two scenarios, the first scenario; maximum transfer capability is computed between two specific nodes. In the second scenario, simultaneous transfer capability is determined when two specific paths are considered simultaneously for the transit. In each scenario three cases correspond to different directions will be studied.

5.1. Scenario A

Three pairs of buses are candidates in this subsection to evaluate the transfer capability. The candidate paths have been selected based on some future plans for power transit between the neighboring countries and other Iranian electric utilities.

The selected three paths are considered between buses (5,19), (67,24) and (11,64) respectively. Computed maximum transfer capability of each path is presented in column (2) of table2 regarding the normal network, i.e. problem (1). It is clear that the maximum transfer capability corresponds to the path (2) is greater than others. When the single contingencies are considered based on proposed formulation in problem (2), the maximum transfer capability is decreased intensively as seen in column (3) of table2. it is clear this formulation considered all of contingencies with the same weight in the objective function and therefore the results are very conservative. This is because problem (2) considers the worst condition and computes the transfer capability based on Min-Max strategy.

Column (4) of table2 is shows the maximum transfer capability corresponds to the formulation in problem 3 and as expected the results are comparable with results of formulation 1. In this computation process four contingencies causing to maximum overload are taken into account.

<table>
<thead>
<tr>
<th>Path number</th>
<th>Maximum transfer capability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Problem (1)</td>
</tr>
<tr>
<td>1</td>
<td>159</td>
</tr>
<tr>
<td>2</td>
<td>242</td>
</tr>
<tr>
<td>3</td>
<td>98.5</td>
</tr>
</tbody>
</table>

Fitness function of each individual in the population is evaluated based on proposed objective function in the formulation (3). This evaluation process computes the expected value of transfer capability through specific paths. In this method the conservatives of method 2 and inaccuracy of method 1 are removed as seen in table (2).

In the consequence, the expected value of maximum transfer capability is the the accurate decision factor to choosing the best transaction. It is clear that in comparison to the results of method (2), the maximum transfer capability is increased.

The path no.2 has the greater maximum transfer capability in all cases and is elected as a best path for power transfer.
5.2. Scenario B: two paths simultaneously

In this section two paths are considered as the simultaneous power transfer paths. This situation leads to the interesting results. For example, two power transfer paths in against direction cause to increase the maximum transfer capability of each path individually.

Three transactions are considered that each of them consists of two paths for power transfer. One of path in each transaction is same as the single path in previous case study.

Maximum transfer capability of each path in different transaction is shown in table 3 in normal network condition. It is clear that this quantity is greater than the corresponding quantities in table 1 when problem 1 is considered. This situation is the result of against direction of paths in each transaction.

Maximum transfer capability in each contingency occurrence as considered in problem (2) is presented in table 4 and 5. Decision factor that is the objective function of problem (3) is shown in table 4. This results show two path for power transfer are more useful than one path because of their flexibility in contingency occurrences and increasing the transfer capability. In addition, result in analyzing the problem (3) is ore reliable than problems (1) and (2).

<p>| Table 3: Maximum transfer capability of paths in different transaction resulted from problem (1) |</p>
<table>
<thead>
<tr>
<th>Transaction</th>
<th>Transaction 1</th>
<th>Transaction 2</th>
<th>Transaction 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path 1</td>
<td>183.5</td>
<td>245</td>
<td>248.5</td>
</tr>
<tr>
<td>Path 2</td>
<td>306</td>
<td>118</td>
<td>254.5</td>
</tr>
<tr>
<td>two paths</td>
<td>489.5</td>
<td>363</td>
<td>503</td>
</tr>
</tbody>
</table>

<p>| Table 4: Maximum transfer capability in each contingency condition in two path transactions in problem (2) |</p>
<table>
<thead>
<tr>
<th>Transaction number</th>
<th>Number of contingencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>609.5</td>
</tr>
<tr>
<td>2</td>
<td>417</td>
</tr>
<tr>
<td>3</td>
<td>504.5</td>
</tr>
</tbody>
</table>

<p>| Table 5: decision factor quantities for different transactions in problem (3) |</p>
<table>
<thead>
<tr>
<th>Transaction number</th>
<th>Decision factor quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>806</td>
</tr>
<tr>
<td>2</td>
<td>495.5</td>
</tr>
<tr>
<td>3</td>
<td>712.5</td>
</tr>
</tbody>
</table>

6. CONCLUSION

In this paper computing of transfer capability in regional power systems studied. The value of transfer capability in different direction can be used as a proper index both in the operation and planning of power system, especially in competitive environment.

To evaluate the transfer capability, in this paper three different formulation are introduced. In the first formulation, the problem solved without considering contingencies in the network. But in the other formulations network contingencies are taken into account based on different approaches. In the first approach, i.e. formulation (2), a conservative formulation based on worse case analysis introduced. The second approach considers the contingencies using probabilistic approach and computes the expected value of transfer capability.

According to advantages of GA, a genetic algorithm solution for solving three different methods is presented.

The result of this solution approach in two different scenarios on Khorasan transmission network is studied. Numerical results show, two paths for power transfer are more useful than one path because of their flexibility in contingency occurrences and increasing the transfer capability. In addition the expected value of transfer capability is a proper index in transfer capability computation.

The obtained results show the effectiveness of the proposed methods. Results can be used in the expansion planning process of the regional power systems properly.

REFERENCES


