3.1. INTRODUCTION

Available Transfer Capability (ATC) is a measure of unutilized capability of transmission system subjected to wheeling transactions without violating transmission constraints at a given time and load. Capacity Benefit Margin (CBM) is incorporated in the test systems by reserving powers in transmission lines. The Transmission Reliability Margin (TRM) is implemented either by making any one of the transmission lines or a generator out of order. CEED problem is obtained by considering both the economy and emission objectives. In the proposed approach, Newton-Raphson method and evolutionary programming algorithm have been used for solving the power flow and combined economic emission dispatch respectively. This bi-objective CEED problem is converted into single objective function using price penalty factor approach. A novel modified price penalty factor is proposed to solve the CEED problem. A non-linear scaling factor is also included in EP algorithm to improve the convergence performance. Assessment of ATC in combined economic emission environment has been tested on IEEE-30 and Indian utility-62 bus systems with line flow constraints. Simultaneous bilateral and multilateral wheeling transactions have been carried out in the test systems for the assessment of ATC. The solutions obtained are quite encouraging and useful in the present deregulated environment.

Open transmission access in electric power industry is now a legal requirement [121]. Deregulation and market competition were introduced in most of the countries like Norway, Chile, Peru, Bolivia, England, the U.S. and now in
India [54,99,111,116]. Operation of power system under deregulated environment presents many technical [97] and economical problems [98]. It seeks to identify deregulation scenarios and technical solutions such as standards and algorithms. Transmission open access to all suppliers and consumers has been mandated in the U.S [116]. Various mathematical models have been developed [35,38,49,70,115] to find Available Transfer Capacity of transmission system.

The central feature dominating the power market in the restructured system is called as power pool. In addition, a range of other trading arrangements such as bilateral and multilateral contracts, forward and future markets and the hour-ahead spot market have made their appearance. Many buyers of power such as industries, housing estates and other complexes may not wish to buy their electricity through the pool and may prefer to make their own power purchase agreements with selected suppliers. This provides motivation for transaction contracts between Independent Power Producer (IPP) and consumers. These transactions could be of two types: either involving just one buyer-seller pair (even if their physical injection and utilization points are multiple) and it is known as bilateral transaction, or bringing together multiple buyers and sellers who group themselves together to enter into a multilateral transaction.

An approach to the optimal power dispatch problem in a structure dominated by bilateral and multilateral transactions have been proposed by Fang and David [32]. Yog Raj Sood et al. describe Evolutionary Programming based Optimal Power Flow (EP-OPF) algorithm for the optimal selection of wheeling option from various feasible options of deregulated power system considering system constraints [134]. The selection of the best possible wheeling transaction has been
determined based on transfer capability and short-term marginal cost in a deregulated power system [132,133].

Since many utilities provide transaction services for wholesale customers, they must know about the post information on ATC of their transmission networks. Such information will help power marketers, sellers and buyers in reserving transmission services. ATC must be rapidly updated for new capacity reservations, schedules or transactions. There is a strong demand to improve the uncertainty of the ATC limits for a number of varying factors, including uncertainties in the location of the delivery and receiving points. The computation of ATC with TRM and CBM has been carried out by Yan-Ou and Chanan Singh in IEEE-24 bus reliability test system [43,129].

In this chapter, ATC with margins is computed for practical power systems in combined economic emission environment. In the proposed approach, Newton-Raphson method and EP algorithm have been used for power flow and combined economic emission dispatch respectively. A modified price penalty factor approach is proposed in this paper to solve the CEED problem. A non-linear scaling factor is also included in EP algorithm to improve the convergence performance. CBM is incorporated by reserving power in transmission lines and TRM is implemented by making either any one of the transmission lines or generator out of order at a time. The proposed EP based CEED algorithm for the computation of ATC with simultaneous bilateral and multilateral transactions is demonstrated on the IEEE-30 and Indian utility-62 bus systems.
3.2. AVAILABLE TRANSFER CAPABILITY

Transfer capability of a transmission system is a measure of unutilized capability of the system at a given time and depends on a number of factors such as the system generation dispatch, system load level, load distribution in network, power transfer between areas and the limit imposed on the transmission network due to thermal, voltage and stability considerations. In the contingency, it is computed after the operation of any automatic devices to secure the system constraints, but before any post-contingency operator initiated the system adjustments.

ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM).

ATC can be expressed as:

\[
\text{ATC} = \text{TTC} - \text{TRM} - \text{Existing Transmission Commitments (including CBM)}
\]

Transmission Reliability Margin is defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secured under a reasonable range of uncertainties.

Capacity Benefit Margin is defined as that amount of transmission transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements.

Utilities would have to determine adequately their ATC’s to insure that system reliability is maintained while serving a wide range of transmission transactions. ATC between and within areas of the interconnected power system and ATC for critical
transmission paths between these areas would be continuously updated and posted changes in scheduled power transfers between the areas.

The ATC principles are stated as follows:

- ATC calculations recognize time-variant power flow conditions and simultaneous transfers and parallel path flow throughout the transmission network.
- ATC calculations must recognize the dependency of it on the points of power injection, the direction of power transfers and the points of power extraction.
- ATC calculations must produce commercially viable results and the computed values must give a reasonably accurate and dependable indication of transfer capabilities available to the electric power market.

ATC calculation is subjected to the following constraints

- Power limit on transmission line

\[ \text{MVAF}_{p,q} \leq \text{MVAF}^\text{max}_{p,q} \]  \hspace{1cm} (3.1)

Where \( \text{MVAF}^\text{max}_{p,q} \) is the maximum rating of transmission line connecting bus \( p \) and \( q \).

- The inequality constraint on voltage of each PQ bus

\[ V_{i\text{min}} \leq V_i \leq V_{i\text{max}} \]  \hspace{1cm} (3.2)

Where \( V_{i\text{min}} \) and \( V_{i\text{max}} \) are minimum and maximum voltage at bus \( i \).

- The inequality constraint on real and reactive power generation \( (P_{gi}, Q_{gi}) \) of each generation \( i \)

\[ P_{gi\text{min}} \leq P_{gi} \leq P_{gi\text{max}} \]  \hspace{1cm} (3.3)

\[ Q_{gi\text{min}} \leq Q_{gi} \leq Q_{gi\text{max}} \]  \hspace{1cm} (3.4)
where $P_{gi}^{min}$, $P_{gi}^{max}$, $Q_{gi}^{min}$ and $Q_{gi}^{max}$ are minimum and maximum value of real and reactive power allowed at generator $i$.

In this work, simultaneous bilateral and multilateral transactions were carried out in the practical test systems to determine their ATC.

3.3. **CEED PROBLEM FORMULATION**

During the computation of ATC, all the generators of the utilities must be held at optimal settings. In this chapter, optimal settings of generators were obtained from CEED environment. The problem formulation of Evolutionary programming based CEED environment was briefly explained in the chapter 2. The mathematical modelling of wheeling transactions is given below:

3.4. **MODELLING OF WHEELING TRANSACTIONS**

A simultaneous wheeling transaction has been included in an n bus system, the seller at the bus $i$ and the buyer with a load at bus $j$. The corresponding wheeling transaction can be represented as $WT(i-j)$, where $i$ and $j$ may be varied from 1 to $n$ and $i$ is not equal to $j$. Let us assume that an Independent Power Producer (IPP) is willing to supply the additional load demand at bus $j$ through the utility transmission system by a wheeling transaction $WT(i-j)$. Then run the EPCEED with all the generators of the utility being held at fixed optimal setting of base case under these conditions. The amount of wheeled power in the network must be within the limits of IPP and satisfy the transmission constraints. In general, the algebraic sum of power delivered by the non-utility generators/Independent Power Producers is equal to the sum of powers taken at different load points. Each bilateral transaction between a seller at bus $i$ and power purchaser at bus $j$ satisfies the following power balance equation.
Multilateral transaction involving more than one seller and/or one buyer can be expressed as:

\[ P_{si} - P_{sj} = 0 \quad k = 1, 2, \ldots, t_k \]  

Where \( P_{si} \) and \( P_{sj} \) represent the power injections into the seller bus \( i \) and the power taken at the buyer bus \( j \) and \( t_k \) is the total number of wheeling transactions.

### 3.5. Step-By-Step Algorithm

The procedure for calculating maximum power transfer capability of a wheeling transaction is as follows.

1. The optimal cost of generation is determined by the EPCEED algorithm (base case) for the given system load.
2. Select the bus number(s) in which the IPP is connected and the load(s) is taken out.
3. Set the load bus counter \( j \), on which additional load to be added.
4. Note the value of real power delivered by the IPP and taken out at the load bus. Thus wheeling transactions are incorporated in the deregulated power system. At a time more than one transaction is also permitted.
5. CBM is incorporated by reserving powers in the selected transmission lines. TRM is implemented by either making the corresponding transmission line or generator as out of order in the network.
6. Find the maximum amount of power that can be transferred without violating network constraints for the corresponding wheeling transaction.
7. Increment the load bus count \( j \) by 1 and if \( j \) is less than or equal to number of buses, then go to step 5.
8. Similarly increment the seller bus \( i \) by 1 until it is less than or equal to \( n \) number of buses.
9. Find the maximum amount of real power (ATC) supplied by the IPP and corresponding cost of generation of utilities for the given load demand including wheeling transactions without violating the transmission constraints.

3.6. SIMULATION RESULTS

The study has been conducted on IEEE-30 bus [3] and Indian utility-62 bus systems [114], slightly modified to represent simultaneous wheeling transaction in a deregulated market. For the present study, reactive power demand at load buses has been taken as constant. In the proposed approach, the minimum generation and cost of the generating units were obtained in combined economic emission environment using evolutionary programming with transmission constraints. The proposed algorithm is applied to IEEE-30 bus and Indian utility-62 bus systems whose data have been given in Appendix A & B. Table 3.1 summarizes the best solution obtained by evolutionary based optimal power flow (EPOPF), combined economic emission dispatch (EPCEED) and modified combined economic emission dispatch (EPMCEED) with line flow constraints for IEEE-30 bus and Indian utility-62 bus systems. The execution time for the proposed method of IEEE-30 and Indian utility-62 bus system is obtained as 52.01 and 285.77 Sec. respectively.

To compute static ATC, best generator settings obtained from the EPMCEED algorithm for the given system load is taken as base case values. Capacity Benefit Margin is incorporated by reserving powers in transmission lines of both the test systems given in Table 3.2. Transmission Reliability Margin is implemented by making third line as out of order in IEEE-30 bus system. It is incorporated in Indian utility-62 bus system by making a generator connected at 37th bus as out of order. The simulation studies were carried out on PIII 700Mhz system in MATLAB environment.
### Table 3.1. Best solution of different methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Price Penalty Factor $/lb</th>
<th>Fuel Cost FC $/hr</th>
<th>Emission Output EC lb/hr</th>
<th>Total Operating Cost $/hr</th>
<th>Total Loss P1 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOPF</td>
<td>-</td>
<td>803.754</td>
<td>421.202</td>
<td>-</td>
<td>6.300</td>
</tr>
<tr>
<td>EPCEED</td>
<td>5.7554</td>
<td>866.653</td>
<td>353.331</td>
<td>3288.689</td>
<td>5.183</td>
</tr>
<tr>
<td>EPMCEED</td>
<td>3.7424</td>
<td>840.219</td>
<td>350.509</td>
<td>2151.570</td>
<td>6.063</td>
</tr>
</tbody>
</table>

### Indian utility-62 bus system

<table>
<thead>
<tr>
<th>Method</th>
<th>Price Penalty Factor $/lb</th>
<th>Fuel Cost FC $/hr</th>
<th>Emission Output EC lb/hr</th>
<th>Total Operating Cost $/hr</th>
<th>Total Loss P1 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOPF</td>
<td>-</td>
<td>16694.363</td>
<td>12506.164</td>
<td>-</td>
<td>69.569</td>
</tr>
<tr>
<td>EPCEED</td>
<td>3.1679</td>
<td>16764.068</td>
<td>12337.371</td>
<td>55829.319</td>
<td>64.658</td>
</tr>
<tr>
<td>EPMCEED</td>
<td>3.0242</td>
<td>16757.249</td>
<td>12333.923</td>
<td>54060.270</td>
<td>64.096</td>
</tr>
</tbody>
</table>

### Table 3.2. Implementation of CBM

<table>
<thead>
<tr>
<th>No.of Lines</th>
<th>From</th>
<th>To</th>
<th>Reserved Power (MVA)</th>
<th>No.of Lines</th>
<th>From</th>
<th>To</th>
<th>Reserved Power (MVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>1.</td>
<td>1</td>
<td>10</td>
<td>05</td>
</tr>
<tr>
<td>2.</td>
<td>2</td>
<td>5</td>
<td>40</td>
<td>2.</td>
<td>11</td>
<td>16</td>
<td>05</td>
</tr>
<tr>
<td>3.</td>
<td>9</td>
<td>10</td>
<td>30</td>
<td>3.</td>
<td>23</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>10</td>
<td>20</td>
<td>12</td>
<td>4.</td>
<td>37</td>
<td>46</td>
<td>05</td>
</tr>
<tr>
<td>5.</td>
<td>28</td>
<td>27</td>
<td>15</td>
<td>5.</td>
<td>47</td>
<td>48</td>
<td>10</td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
<td></td>
<td>6.</td>
<td>14</td>
<td>19</td>
<td>10</td>
</tr>
</tbody>
</table>
3.6.1. IEEE-30 bus system

The EPMCEED algorithm was applied to IEEE-30 bus system with 6 generating units and 41 transmission lines with four tap changing transformers. The total system load demand is 283.4 MW. For the base case, best generation of IEEE-30 bus generating units obtained from EPMCEED algorithm is presented in the Fig.3.1. The total operating cost of combined economic dispatch is obtained as 2151.570 $/hr.

Fig 3.1. Best generator settings of EPMCEED method – IEEE-30 bus system

Results of Table 3.1 reveal that the price penalty factor (h) approach gives only the approximate value of total operating cost for their corresponding load demand. Hence in this work, a modified price penalty factor (h_m) approach is proposed to give exact total operating cost.
The computational procedure of proposed modified price penalty factor for IEEE-30 bus system is explained as follows. The ratio between the maximum fuel and emission costs of six generating units were found and arranged in ascending order.

\[ h_i = [ h_2 \ h_1 \ h_4 \ h_5 \ h_3 \ h_6 ] \]

\[ h_i = [ 1.7342 \ 3.5258 \ 5.7554 \ 5.9324 \ 5.9834 \ 6.3000 ] \]

The corresponding maximum limits of generating units are given by

\[ P_{G}^{\text{max}} = [ 80 \ 200 \ 35 \ 30 \ 50 \ 40 ] \]

For a load of \( P_d \) MW starting from the lowest \( h_i \) value unit, the maximum capacity (\( m \)) of the units is added one by one and when this total equals or exceeds the load, \( h_i \) associated with the last unit in the process is price penalty factor [63].

\[ m = [ 80 \ 280 \ 315 \ 345 \ 395 \ 435 ] \]

For \( P_d = 283.4 \) MW, \((80+200+35) \text{ MW} > 283.4 \text{ MW} \).

Hence price penalty factor \( (h) \) is determined as 5.7554 for IEEE 30 bus system. Even though the price penalty factor was computed for 283.4 MW but it gives the value up to a load demand of 315 MW. So the modified price penalty factor is computed by interpolating the values of \( h_i \) for second and third generating units by satisfying the corresponding load demand.

\[ h_m = 3.5258 + \frac{5.7554 - 3.5258}{315 - 280} \times (283.4 - 280) \]

\[ h_m = 3.7424 \]

By incorporating modified price penalty factor approach, the operating cost savings of approximately 1137 $/hr was obtained for IEEE-30 bus system given in Table 3.1.
The following case studies are carried out for computing static ATC with margins subjected to various wheeling transactions in a combined economic emission environment.

**Case 1:**

Let us assume that IPP of 50 MW maximum capacity is connected at bus no.30. All the generators of the IEEE test system must be held at best setting values obtained from EPMCEED method. The buyer is interested to have a bilateral transaction in all the buses of 30-bus system. Fig. 3.2 presents the maximum allowed load (TTC) that can be supplied by IPP through various wheeling transactions at different load points. The real power (ATC) to be wheeled with CBM and TRM when IPP is connected at the 30th bus is shown in Fig.3.2.

![Diagram of maximum allowed load supplied by IPP through wheeling transactions](image-url)

**Fig. 3.2.** Maximum allowed load supplied by IPP through wheeling transactions WT (30-j)
This information helps the pool controller to encourage feasible wheeling transactions without violating system reliability and economy in combined economic emission environment.

Case 2:
Let us consider that a seller and buyer pair is interested to transfer real power between 14th bus to 22nd bus, 16th bus to 8th bus, 25th bus to 5th bus and 15th bus to 24th bus simultaneously. It is found that ATC obtained is about 17 MW, 10 MW, 30 MW and 15 MW respectively for the above wheeling transactions without violating the transmission constraints.

Case 3:
Let us consider that a seller and buyers are interested in transferring real power along with four simultaneous bilateral in case 2 and a multilateral transaction between buses 18 and 21 to load buses 6, 12, 27 and 30 respectively. The summation of wheeling real powers taken out at the load buses is equal to the power supplied by IPP. ATC with margins obtained for the above transactions is 10 MW, 7 MW, 4 MW and 5 MW in the corresponding load buses. The lines got congested after transferring 26 MW of real power along with four simultaneous bilateral transactions in case 2.

3.6.2. Indian Utility - 62 bus system

To validate the performance of the proposed algorithm, Indian utility-62 bus system consisting of 19 generators, 89 (220kV) lines with 11 tap-changing transformers has been considered. The total load demand is 2909 MW. For the corresponding load demand, best generation of Indian utility-62 bus generating units obtained from the proposed evolutionary programming algorithm is given in Fig.3.3. Best solution obtained by different methods for Indian Utility 62 bus system is given in Table 3.1. The total
operating cost of the above test system with EPMCEED algorithm is obtained as 54060.270 $/hr. From the results of Table 3.1, it is justified that modified price penalty factor approach gives the exact minimum dispatch solution. By incorporating modified price penalty factor approach, the operating cost savings of approximately 769 $/hr was obtained.

Fig 3.3. Best generator settings of EPMCEED method – Indian utility 62 bus system

The following case studies are carried out for computing static ATC with margins when subjected to simultaneous bilateral and multilateral transactions.

Case 1:
Let us consider a seller and buyer pair is interested to have four bilateral real power transactions between 28th bus to 44th bus, 35th bus to 16th bus, 50th bus to 10th bus and 30th bus to 48th bus simultaneously. It is observed that ATC obtained is about 35 MW, 5 MW, 4 MW and 36 MW respectively for the above wheeling transactions without violating the transmission constraints.
Case 2:
Let us consider that a seller and buyers are interested in transferring real power along with four simultaneous bilateral in case 2 and a multilateral transaction between buses 36 and 42 to load buses 12, 24, 54 and 60 respectively. The summation of wheeling real powers taken out at the load buses is equal to the power supplied by IPP. ATC with margins obtained for the above transactions is 20 MW, 10 MW, 51 MW and 68 MW in the corresponding load buses. The lines got congested after transferring 149 MW of real power along with four simultaneous bilateral transactions in case 2.

Case 3:
Let us consider that sellers and buyers are interested in transferring real power between them by two multilateral transactions. For the first multilateral transaction, the seller buses are 9, 18, 30 and buyer buses are 10, 15, 36, 60 respectively. The static ATC determined for the first multilateral transaction is 63 MW using the proposed algorithm with line flow constraints. For the second multilateral transaction, the seller buses are 33 & 15 and buyer buses are 19, 22 & 12 respectively. The static ATC value obtained with the proposed algorithm is 54 MW for the second multilateral transaction.

3.7. CONCLUSION

In this work, the transfer capabilities of the test systems with and without margins were calculated with wheeling transactions. It represents the amount of additional power to be wheeled in the transmission system without affecting the system security. During the computation of the transfer capability, the base case generator settings of the test systems were obtained using evolutionary programming algorithm. The results obtained are found to be useful in determining the magnitude of feasible wheeling transactions in a combined economic emission environment.