Chapter - 4
DETERMINATION OF SHORT RUN MARGINAL COST

4.1. INTRODUCTION

Short run marginal cost (SRMC) of wheeling transactions is defined as the difference between the incremental costs of the buses for producing an additional mega watt at each bus. Determination of SRMC using conventional methods suffers due to the presence of non-smooth fuel cost generators in the modern deregulated utilities. Hence in this work, Evolutionary Programming (EP) based OPF solution has been developed for obtaining optimal generator settings with four non-smooth fuel functions. System transmission loss and penalty factor at each and every bus are computed using the OPF solution. Further bus incremental cost at all the buses is computed using penalty factors. Generalized loss coefficients are also obtained from OPF solution and they are the functions of the system operating state with non-smooth fuel functions.

Rana Mukherji et al. calculated marginal cost of wheeling transactions and non-utility generation options using OPF for practical utilities and IEEE test systems [95]. Researcher Richard computed SRMC for different test systems and explained international experience in transmission system pricing [96]. El-Keib and Ma calculated SRMC for power production taking into account real and reactive powers and demonstrated with IEEE test systems [31]. A mathematical model of electric power system has been developed to understand marginal prices for consumers and generators in competitive generation market and verified with a practical power system [92]. Yog Raj Sood et al. presented different methods of transmission pricing for wheeling transactions under deregulated environment of power system [131].
SRMC for feasible bilateral transactions are computed from the OPF solution. Economic Load Dispatch (ELD) problem is the sub problem of OPF. The main objective of ELD is to minimize the fuel cost while satisfying the load demand with transmission constraints. The classical lambda iteration method has been used to solve the ELD problem. This method has used equal increment cost criterion for systems without transmission losses and penalty factors using $B_{nn}$ matrix for considering the losses. Other methods such as gradient, newton, linear programming and interior point have also been applied to solve the ELD problem [124]. Traditionally, thermal units are using a single fuel and hence the ELD of such generating units have a single cost function. In practical environment, thermal units are using multiple fuels like coal, natural gas and oil. The multiple fuel options lead the objective function of the ELD to piecewise quadratic cost functions [74]. Hopfield neutral networks are used to solve the ELD problem with piecewise quadratic functions [68,89]. Jayabarathi et al. have presented the application of evolutionary programming algorithm to economic dispatch of ten-generator units with multiple fuel options [60]. Baskar et al. have presented a two-phase hybrid genetic algorithm for solving the ELD problem with multiple fuel options [9]. In the hybrid scheme, simple real coded genetic algorithm was used as a base level search and local optimization was carried out by direct search method. Lee and Yang have presented a comparative study among three evolutionary algorithms in solving the ELD problem with piecewise quadratic functions [67].

The fuel cost function becomes more non-linear when valve point loading effects are included [104]. Piecewise quadratic cost functions were used to reflect the effects of valve point loadings instead of a single cost function and the possible fuel changes during
power plant operations. Moreover, a non-linear equality power plant constraint was incorporated to estimate the transmission losses with loss coefficient method instead of assuming them as constant [69]. Recently combined cycle co-generation (CCCP) plants have shown their importance in both developing and developed countries in order to improve the efficiency of generation. The fuel cost characteristics of the CCCP is non-smooth and non-differentiable [20,42,108,118]. Thus the non-linearity in the problem is further increased. All these methods consider the ELD problem as a convex optimization problem and assume that the whole of the unit operating range between the minimum generation limit ( \( P_{g,\min} \)) and the maximum generation limit ( \( P_{g,\max} \)) is available for operation. In practical systems, the operating range of all on-line units is restricted by their ramp rate limits [58,94].

In this work, SRMC of feasible bilateral transactions are determined using an EP based OPF algorithm. The system losses and penalty factors at different buses are computed from the OPF results. Bus incremental costs of the buses are found out from the penalty factors. In addition, generalized loss coefficients matrix is found out from the OPF results. The developed EP based OPF algorithm is capable to handle non-smooth fuel functions. In the proposed EP algorithm, mutation is changing non-linearly with respect to the number of generations to avoid premature conditions. The feasibility of the algorithm for the computation of SRMC is demonstrated using the IEEE 30 bus and Indian utility 62 bus systems.
4.2. SHORT RUN MARGINAL COST

The short run marginal cost of wheeling between two buses (i-j) is defined as the product of difference in the costs of producing an additional Mega Watt at each bus [95] and the magnitude of transaction $A_T$. It is expressed as follows.

$$SRMC = (\lambda_j - \lambda_i) \times A_T \text{ $/hr$}$$  \hspace{1cm} (4.1)

where

- $\lambda_j$ – incremental cost of $j^{th}$ bus in $$/MWhr where power is taken out due to feasible transaction.
- $\lambda_i$ – incremental cost of $i^{th}$ bus in $$/MWhr where power is injected due to feasible transaction.
- $A_T$ – magnitude of feasible transaction in MW.

These marginal costs can be obtained from OPF solutions. Conventional methods normally used to solve OPF solution, require partial derivatives of the fuel cost function ($F(P_g)$) with respect to real power generation ($P_g$) and hence incremental costs at all the buses can be determined. It is difficult to determine SRMC of wheeling transaction between two buses, when the generators of the system have non-smooth fuel cost functions. Due to the above reason, AI techniques are widely used to find the solution of OPF [118]. AI techniques are not using partial derivatives to obtain OPF solution. In this chapter, an evolutionary programming algorithm is developed for the determination of SRMC of wheeling transactions using OPF solution. Initially EP based OPF solution is obtained with the optimal operating state of generators. From the OPF results, the load currents at different buses, the total current and rate of change of losses at different buses are evaluated [124]. From the losses, the penalty factors of the buses are determined. The penalty factor of bus $i$ is given by

$$P_n = 1/(1-(\delta P_{bus}/\delta P_i))$$  \hspace{1cm} (4.2)
The relationship between incremental costs at any two buses, i and j is given by [124]

\[ P_i \cdot \lambda_i = P_j \cdot \lambda_j \]  

(4.3)

There is no requirement that bus 'i' is a generator bus. From the results of OPF (load currents at different buses, the total load current) generalized loss coefficients are evaluated [124]. It should be noted that the generalized loss coefficients are the functions of the system operating state with non-smooth fuel functions. If the network effects are included using a network model or loss coefficients, bus i might be a load bus or a point where power is delivered to an interconnected system. The incremental cost of power at bus 'i' is given by

\[ \lambda_i = (P_i/P_n) \cdot \lambda_j \]  

(4.4)

After determining the incremental costs at different buses, SRMC of wheeling transactions between two buses is determined.

4.3. OPTIMAL POWER FLOW

Optimization of cost of generation has been formulated based on classical OPF problem with line flow constraints. The complete OPF is capable of establishing schedules for many controllable quantities in the bulk power system (i.e., the generation and transmission system), such as transformer tap positions, VAR generation schedules, etc. For a given power system network, the optimization cost of generation is given by the equation (4.5).

\[ F = \text{Min} \sum_{i=1}^{N_g} f_i(P_{g_i}) \]  

(4.5)

where  

- \( F \) is the optimal cost of generation
- \( f_i(P_{g_i}) \) is the fuel cost of the \( i^{th} \) generator
- \( N_g \) represents total number of generators connected in the network.
The cost is optimized with the following power system constraint

\[ \sum_{i=1}^{N_q} P_i^d = P_d + P_i \]  

(4.6)

where \( P_d \) is the total load of the system and \( P_i \) is the transmission losses of the system.

- The power flow equation of the power network

\[ g(\vert \psi \vert, \delta) = 0 \]

where

\[ g(\vert \psi \vert, \delta) = \begin{vmatrix} P_i (\vert \psi \vert, \delta) - P_i^{\text{net}} \\ Q_i (\vert \psi \vert, \delta) - Q_i^{\text{net}} \\ P_m (\vert \psi \vert, \delta) - P_m^{\text{net}} \end{vmatrix} \]  

(4.7)

where \( P_i \) and \( Q_i \) are respectively calculated real and reactive power for PQ bus \( i \).
\( P_i^{\text{net}} \) and \( Q_i^{\text{net}} \) are respectively specified real and reactive power for PQ bus \( i \).
\( P_m \) and \( P_m^{\text{net}} \) are respectively calculated and specified real power for PV bus \( m \).
\( \vert \psi \vert \) and \( \delta \) are voltage magnitude and phase angles of different buses.

- The inequality constraint on real power generation \( P_i \) of each generation \( i \)

\[ P_i^{\text{min}} \leq P_i \leq P_i^{\text{max}} \]  

(4.8)

- Ramp-rate constraint

The ramp-rate constraint restricts the real power operating range of generator to the effective lower limit \( P_i^{\text{min}} (R) \) and upper limit \( P_i^{\text{max}} (R) \) respectively [58]. These limits are defined as

\[ P_i^{\text{min}} (R) = \max \{ P_i^{\text{min}}, P_i^0 - DR_i \} \]  

(4.9 a)

\[ P_i^{\text{max}} (R) = \min \{ P_i^{\text{max}}, P_i^0 + UR_i \} \]  

(4.9 b)

where \( P_i^0 \) is the power generation of unit \( i \) at previous hour and \( DR_i \) and \( UR_i \) are the ramp-rate limits of unit \( i \) as generation decreases and increases respectively.

Hence the ramp rate constraint is stated as

\[ P_i^{\text{min}} (R) \leq P_i \leq P_i^{\text{max}} (R) \]  

(4.9 c)
The inequality constraint on voltage of each PQ bus

\[ V_{i,\min} \leq V_i \leq V_{i,\max} \]  \hspace{1cm} (4.10)

where \( V_{i,\min} \) and \( V_{i,\max} \) are respectively minimum and maximum voltage at bus \( i \).

- Power limit on transmission line

\[ \text{MVA}_{p,q} \leq \text{MVA}_{p,q}^{\max} \]  \hspace{1cm} (4.11)

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

In the proposed approach, the following four types of fuel cost functions of generators are considered.

The conventional quadratic fuel cost function of generating units is given by

\[ f_i(P_g)_{\text{quadratic}} = \sum_{i=1}^{n_g} (a_i P_g^2 + b_i P_g + c_i) \]  \hspace{1cm} S/hr

where \( P_g \) is the real power output of an \( i^{th} \) generator. \( a_i, b_i, \) and \( c_i \) are the fuel cost coefficients.

By taking into account multiple fuel option, conventional quadratic cost function becomes piecewise functions. The operating cost of multiple fuel option is given by

\[ f_i(P_g) = \begin{cases} a_{i1} P_g^2 + b_{i1} P_g + c_{i1} & \text{if } P_{g,i}^{\min} \leq P_g < P_{g,i}^{\max} \\ a_{i2} P_g^2 + b_{i2} P_g + c_{i2} & \text{if } P_{g,i}^{\max} \leq P_g < P_{g,i}^{\max} \end{cases} \]  \hspace{1cm} (4.13a)

\[ \ldots \ldots \]  \hspace{1cm} (4.13b)

\[ a_{im} P_g^2 + b_{im} P_g + c_{im} & \text{if } P_{g,i,n-1} \leq P_g < P_{g,i,n}^{\max} \]  \hspace{1cm} (4.13c)

where

- \( a_{im}, b_{im}, c_{im} \) are the cost coefficients of the \( i^{th} \) generator at the \( n^{th} \) power level.
- \( P_{g,i}^{\min} \) and \( P_{g,i}^{\max} \) are the minimum and maximum real power generation of the \( i^{th} \) generator.

By taking into account valve point loading effects, the fuel cost function of generating units consists of sine components [104]. It is given by,

\[ f_i(P_g)_{\text{valve}} = [\text{Conventional quadratic } f_i(P_g)] + \left| d_i \sin(e_i (P_g - P_{g,i}^{\min})) \right| \]  \hspace{1cm} S/hr

where \( d_i \) and \( e_i \) are fuel cost coefficients of \( i^{th} \) generator with valve point effects.
The fuel cost function of combined cycle co-generation plant \([20,42,108,118]\) is obtained as

\[
f_i (P_{gi})_{CCC} = b_i P_{gi} + c_i \quad \text{/hr} \quad \text{Linear region} \quad (4.15 \text{ a})
\]

\[
= K \quad \text{/hr} \quad \text{Constant region} \quad (4.15 \text{ b})
\]

where

\(b_k, c_k\) are the cost coefficients of CCCP in linear region and

\(K\) is the cost coefficient of CCCP in constant region.

### 4.4. ALGORITHM OF THE PROPOSED METHOD

The algorithm of the proposed method for the computation of SRMC is given as follows.

Step 1: Prepare the system data using line data, bus data and generator data.

Step 2: Run the EP based optimal power flow with non-smooth fuel cost functions and calculate the optimal generators schedule.

Step 3: Set the generators with their optimal settings and run load flow and then calculate the load currents at different buses, the total load current and losses of the system.

Step 4: Calculate penalty factors of all the buses using the Equation (4.2) and the results of step 3.

Step 5: Compute bus incremental cost of all the buses using Equations (4.3 & 4.4).

Step 6: Select the feasible transaction (MW) and the bus numbers between which the wheeling takes place.

Step 7: Find the SRMC of the feasible wheeling transaction using Equation (4.1).

Step 8: For any other feasible wheeling transactions, go to the step 4. Otherwise stop.
4.5. SIMULATION RESULTS

In the proposed algorithm, marginal costs of feasible wheeling transactions from the bus \( i \) to \( j \) were calculated for IEEE-30 bus and Indian utility 62-bus test systems with generators having non-smooth fuel functions. The optimal generation and minimum cost of the generating units with ramp rate limits were obtained using evolutionary programming by satisfying the transmission constraints. In the proposed EP algorithm, mutation is changing non-linearly with respect to the number of generations to avoid premature conditions. The ramp rate limits restrict the operating range of the lower and upper real power limits of generating units.

To compute the magnitude of feasible transactions (MW), secure and reliable margins were considered. Transmission line powers were reserved in 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 and in Indian utility-62 bus system by making a generator connected at 37th bus as out of order.

The losses, penalty factors and incremental costs of all the buses were computed from the EP based OPF solution. The generalized loss coefficients \((B_{ij})\) of two test systems with four non-smooth fuel functions were computed. The simulation studies were carried out on P-III 700 MHz system in MATLAB environment.

4.5.1. IEEE-30 bus System

IEEE-30 bus system consists of six generating units, 41 transmission lines, 4 tap changing transformers and 2 injected VAR sources. The total system load demand is 283.4 MW. The cost coefficients of IEEE-30 bus system are slightly modified to incorporate non-smooth fuel cost functions as shown in Appendix. A. It is inferred that
the first generator is assumed to be CCCP, second generator has piecewise and two
generators have valve point loading and two, quadratic fuel functions respectively. The
ramp rate limits of generating units are also given in Appendix. A.

Let us assume that Independent Power Producer of 50 MW maximum capacity is
connected at bus no.30. All the generators of the system must be held at best setting
values obtained from EP based OPF method. The buyer is now interested to establish a
feasible transaction between bus 30 to rest of the buses in the system. The bus
incremental costs and magnitude of feasible transactions with security and reliability
margins and SRMC of all the buses were given in Table 4.1. It has been inferred that the
SRMC is positive for certain transactions and negative for the rest of the cases. Based on
the results so obtained, the Independent System Operator can take an optimal decision
and if needed a priority list in encouraging feasible bilateral transactions. The generalized
loss coefficients of the system were given in Table 4.2.

4.5.2. Indian utility 62-bus System

The proposed algorithm was demonstrated with Indian utility 62-bus system
having 19 generating units, 89 transmission lines, 11 tap changing transformers and
9 injected VAR sources. The total system load demand is 2909 MW. The one-line
diagram of Indian utility system is shown in Appendix B. The cost coefficients of
Indian utility 62-bus system are slightly modified to incorporate non-smooth fuel cost
functions as shown in Appendix. B. It is inferred that the three generators are assumed to
be CCCP and three, piecewise quadratic fuel functions respectively and five generators
are having valve point loading and all other generating units having quadratic fuel
functions. The ramp rate limits of corresponding generating units are also given in Appendix B.

Table 4.1. Bus incremental costs, Magnitude of feasible transactions and SRMC – IEEE-30 bus system

<table>
<thead>
<tr>
<th>Bus No.</th>
<th>Incremental Cost ($/MW-hr)</th>
<th>Magnitude of feasible transaction (MW)</th>
<th>SRMC ($/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>3.327</td>
<td>40</td>
<td>-11.32</td>
</tr>
<tr>
<td>2.</td>
<td>3.439</td>
<td>40</td>
<td>-6.84</td>
</tr>
<tr>
<td>3.</td>
<td>3.700</td>
<td>40</td>
<td>3.60</td>
</tr>
<tr>
<td>4.</td>
<td>3.755</td>
<td>40</td>
<td>5.80</td>
</tr>
<tr>
<td>5.</td>
<td>3.920</td>
<td>40</td>
<td>12.40</td>
</tr>
<tr>
<td>6.</td>
<td>4.000</td>
<td>40</td>
<td>15.60</td>
</tr>
<tr>
<td>7.</td>
<td>3.630</td>
<td>40</td>
<td>0.80</td>
</tr>
<tr>
<td>8.</td>
<td>3.624</td>
<td>33</td>
<td>0.46</td>
</tr>
<tr>
<td>9.</td>
<td>3.650</td>
<td>36</td>
<td>1.44</td>
</tr>
<tr>
<td>10.</td>
<td>3.630</td>
<td>08</td>
<td>0.16</td>
</tr>
<tr>
<td>11.</td>
<td>3.612</td>
<td>36</td>
<td>0.07</td>
</tr>
<tr>
<td>12.</td>
<td>3.640</td>
<td>26</td>
<td>0.78</td>
</tr>
<tr>
<td>13.</td>
<td>3.580</td>
<td>26</td>
<td>-0.78</td>
</tr>
<tr>
<td>14.</td>
<td>3.690</td>
<td>20</td>
<td>1.6</td>
</tr>
<tr>
<td>15.</td>
<td>3.630</td>
<td>17</td>
<td>0.34</td>
</tr>
<tr>
<td>16.</td>
<td>3.690</td>
<td>13</td>
<td>1.04</td>
</tr>
<tr>
<td>17.</td>
<td>3.630</td>
<td>09</td>
<td>0.18</td>
</tr>
<tr>
<td>18.</td>
<td>3.650</td>
<td>11</td>
<td>0.44</td>
</tr>
<tr>
<td>19.</td>
<td>3.620</td>
<td>10</td>
<td>0.10</td>
</tr>
<tr>
<td>20.</td>
<td>3.620</td>
<td>09</td>
<td>0.09</td>
</tr>
<tr>
<td>21.</td>
<td>3.180</td>
<td>08</td>
<td>-3.44</td>
</tr>
<tr>
<td>22.</td>
<td>3.610</td>
<td>08</td>
<td>0.00</td>
</tr>
<tr>
<td>23.</td>
<td>3.660</td>
<td>14</td>
<td>0.7</td>
</tr>
<tr>
<td>24.</td>
<td>3.660</td>
<td>11</td>
<td>0.55</td>
</tr>
<tr>
<td>25.</td>
<td>3.650</td>
<td>17</td>
<td>0.68</td>
</tr>
<tr>
<td>26.</td>
<td>3.580</td>
<td>12</td>
<td>-0.36</td>
</tr>
<tr>
<td>27.</td>
<td>3.630</td>
<td>40</td>
<td>0.80</td>
</tr>
<tr>
<td>28.</td>
<td>3.630</td>
<td>40</td>
<td>0.80</td>
</tr>
<tr>
<td>29.</td>
<td>3.610</td>
<td>29</td>
<td>0.00</td>
</tr>
<tr>
<td>30.</td>
<td>3.610</td>
<td>50</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 4.2. Generalized Loss Coefficients – IEEE 30 bus system

<table>
<thead>
<tr>
<th>0.000218</th>
<th>0.000102</th>
<th>0.000010</th>
<th>-0.000010</th>
<th>0.000001</th>
<th>0.000027</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000102</td>
<td>0.000187</td>
<td>0.000004</td>
<td>-0.000015</td>
<td>0.000003</td>
<td>0.000031</td>
</tr>
<tr>
<td>0.000010</td>
<td>0.000004</td>
<td>0.000430</td>
<td>-0.000134</td>
<td>-0.000160</td>
<td>-0.000108</td>
</tr>
<tr>
<td>-0.000010</td>
<td>-0.000015</td>
<td>-0.000134</td>
<td>0.000224</td>
<td>0.000097</td>
<td>0.000051</td>
</tr>
<tr>
<td>0.000001</td>
<td>0.000030</td>
<td>-0.000160</td>
<td>0.000097</td>
<td>0.000256</td>
<td>0.000000</td>
</tr>
<tr>
<td>0.000027</td>
<td>0.000031</td>
<td>-0.000108</td>
<td>0.000051</td>
<td>0.000000</td>
<td>0.000359</td>
</tr>
</tbody>
</table>
The following case studies are carried out for determining SRMC when subjected to wheeling transactions.

Case 1:

The Independent Power Producer of 100 MW maximum capacity is connected at bus no. 55. All the generators of the system must be held at best setting values obtained from EP based OPF method. The buyer is now interested to establish a feasible transaction between bus 55 to rest of the buses in the system. SRMC of all the buses of feasible wheeling transactions with secure and reliable margins were given in Fig. 4.1. It has been inferred that the SRMC is positive for certain transactions and negative for the rest of the cases. It is concluded that the wheeling transactions with negative values of SRMC favour the system. The generalized loss coefficients of the system obtained from OPF solution were given in Table 4.3.

![Graph](image)

**Fig. 4.1.** SRMC of all the feasible transactions between bus 55 and rest of the buses – Indian Utility-62 bus system
Table 4.3. Generalized Loss Coefficients – Indian utility-62 bus system

```
0.0115 0.0097 0.0092 0.0119 0.0099 0.0060 -0.0039 -0.0034 -0.0068 0.0069 -0.0057 -0.0100 -0.0041 0.0007 -0.0029 -0.0025 -0.0052 -0.0004 -0.0020
0.0097 0.0107 0.0099 0.0097 0.0080 0.0056 -0.0030 -0.0031 -0.0053 -0.0058 -0.0063 -0.0027 -0.0041 -0.0032 -0.0031 -0.0026 -0.0038 -0.0012 -0.0017
0.0092 0.0099 0.0120 0.0092 0.0078 0.0056 -0.0029 -0.0030 -0.0051 -0.0056 -0.0064 -0.0017 -0.0041 -0.0035 -0.0032 -0.0027 -0.0036 -0.0013 -0.0017
0.0119 0.0097 0.0092 0.0150 0.0105 0.0061 -0.0043 -0.0035 -0.0074 -0.0073 -0.0056 -0.0125 -0.0042 0.0002 -0.0029 -0.0026 -0.0058 -0.0002 -0.0022
0.0099 0.0080 0.0078 0.0105 0.0119 0.0065 -0.0043 -0.0033 -0.0077 0.0074 -0.0051 -0.0149 -0.0040 0.0012 -0.0027 -0.0023 -0.0060 0.0001 -0.0021
0.0060 0.0036 0.0056 0.0061 0.0065 0.0085 -0.0020 0.0018 0.0005 0.0002 0.0004 0.0035 0.0000 -0.0005 -0.0005 -0.0005 -0.0005 -0.0004 -0.0010
-0.0039 -0.0030 -0.0029 -0.0043 -0.0043 -0.0020 0.0093 0.0059 0.0002 0.0001 0.0002 0.0012 0.0001 -0.0002 -0.0004 -0.0003 -0.0004 -0.0006 -0.0000
-0.0034 -0.0031 -0.0030 -0.0035 -0.0033 -0.0018 0.0059 0.0058 0.0142 0.0128 0.0082 0.0198 0.0024 -0.0019 -0.0001 -0.0008 -0.0000 -0.0004 -0.0002
-0.0068 -0.0053 -0.0051 -0.0074 -0.0077 -0.0047 0.0005 0.0002 0.0082 0.0100 0.0149 -0.0025 0.028 0.029 0.0002 -0.0008 0.0017 -0.0005 -0.0015
-0.0069 -0.0058 -0.0056 -0.0073 -0.0074 -0.0050 0.0002 0.0001 0.0198 0.0143 -0.0025 0.1234 0.018 -0.0256 -0.0014 -0.0013 0.0104 -0.0009 -0.0016
-0.0057 -0.0063 -0.0064 -0.0056 -0.0051 -0.0049 0.0004 0.0002 0.0024 0.0024 0.0028 0.0018 0.0173 0.0107 0.0071 0.0035 0.012 -0.0019 -0.0007
-0.0100 -0.0027 -0.0017 -0.0125 -0.0149 -0.0043 0.0035 0.0012 -0.0019 -0.0008 0.0029 -0.0024 0.0107 0.0544 0.0078 0.0034 0.0086 -0.0005 -0.0017
-0.0041 -0.0041 -0.0041 -0.0042 -0.0040 -0.0031 0.0000 0.0000 -0.0001 -0.0000 -0.0001 -0.0014 0.0071 0.0078 0.0111 0.0055 0.010 0.0015 -0.0021
-0.0007 -0.0032 -0.0035 0.0002 0.0012 -0.0017 -0.0005 -0.0002 -0.0008 -0.0010 -0.0008 -0.0013 0.0035 0.0034 0.0055 0.0114 -0.0094 0.0054 -0.0006
-0.0029 -0.0031 -0.0032 -0.0029 -0.0027 -0.0022 -0.0005 -0.0004 0.0017 0.0014 0.0012 0.0086 0.0110 -0.0094 0.0096 0.0052 0.0096 0.0035 -0.0029
-0.0025 -0.0026 -0.0027 -0.0026 -0.0023 -0.0018 -0.0005 -0.0003 -0.0005 -0.0009 -0.0019 -0.0005 0.0015 0.0054 0.0035 0.0038 0.0002 -0.0038 -0.0037
-0.0052 -0.0038 -0.0036 -0.0058 -0.0060 -0.0032 -0.0004 -0.0000 0.0015 0.0016 -0.0007 -0.0017 0.021 -0.0006 0.0029 0.0037 -0.0031 -0.0012 -0.0060
-0.0004 -0.0012 -0.0013 -0.0002 -0.0001 -0.0004 -0.0006 -0.0004 0.0142 0.0128 0.0082 0.0198 0.0024 -0.0019 -0.0001 -0.0008 -0.0012 0.0152 0.0000
-0.0020 -0.0017 -0.0017 -0.0022 -0.0021 -0.0010 -0.0000 0.0002 -0.0019 -0.0008 0.0029 0.00256 0.0107 0.0544 0.0078 0.0034 0.0060 0.0000 0.0090
```
Case 2:

Let us consider two multilateral transactions are carried out to determine their corresponding SRMC. First multilateral transaction is carried out between 12,21,33 buses and 13,18,39 and 63 buses respectively. The value of SRMC obtained by the proposed algorithm is 330 $/hr. The second multilateral transaction is carried out between 36 & 15 buses and 18,22 and 25 buses respectively. The computed SRMC value for the second multilateral transaction is −39 $/hr. From the results, it is inferred that second multilateral transaction favours the system.

4.6. CONCLUSION

SRMC of the feasible wheeling transactions were computed using evolutionary programming based algorithm. It was observed that negative SRMC values were obtained for certain transactions. This means that they are favouring the transmission network ie., reducing congestion and losses. Such wheeling transactions are encouraged in the deregulated power industry. The developed algorithm is also capable of handling non-smooth fuel cost functions of the generating units.