# Penalty Quoted Cost Approach for Loss Allocation in a Transmission line by Considering the Mutual Inductance

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***Abstract*: In deregulated electricity market, there is a significance of Loss and Cost Allocation due to transmission. The real power loss from the generators and its associated cost is allocated to the concerned parties in a fair manner by Independent System Operator (ISO). In the cost allocation process there is a participation of generators and loads. The effective part of the paper is there is an impact of mutual inductance (MI) which involves in transmission line in transmission cost/loss allocation phenomena for multilateral contracts is illustrated using a test bus system. To determine the effect of mutual inductance penalized quoted cost (PQC) based approach has discussed. Effect of mutual inductance is tested on an IEEE-4bus system. The simulation results are obtained using MATLAB R2014a. The result shows that there is a significant impact on transmission loss due to mutual inductance which cannot be neglected in the Allocation of loss process.***

***Index Terms: penalized quoted cost, loss/cost allocation, multilateral contracts, mutual inductance and independent system operator.***

## I. INTRODUCTION

The Deregulation is an entity which creates changes to encourage competition wherever it is necessary. In power system, deregulation is frequently used and is very common in regulatory and economic aspects. It is converting the rules the government is setting up to control the running of electric supply industries. In these industries it takes part of the original structure and arranges into other form for better efficiency and performance. It is altering the franchise rule monopoly that effect in what way the electric companies work and customers buy electric power services. The deregulation of the electric utility industry wants IPP to be within the transmission system. For transmitting the power from generation to consumption there must be a common transmission network between power producers, sellers and buyers.

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To ignore the huge investment the natural monopoly interconnected transmission system is considered. The deregulation power flow method are slightly different compared to regulation market. In trying to get profits, benefits and cheaper sources causes overloading in transmission network, increase in thermal voltage and no system security. Thus to control the transmission network operation, performance and security system operator, grid operator is required. There are new entities that can function independently which is created by electricity restructuring and those entities in deregulated electricity market are generating companies, transmission companies distribution companies and independent system operator.

Generating companies (GENCOs) generate electricity and also sell reactive powers and electricity to the entities. Transmission companies (TRANSCOs), transmit electricity to the consumers through transmission network. Distribution companies (DISCOs) distribute the electricity to customers in specified region. From spot markets the electricity will be purchased and supplied to the customers. A customer cannot purchase electricity in a restructure system but they can obtain by bidding in spot market. Independent system operator is established since a competitive market requires independent operation and grid control. It is an entity that does not participate in market trades and maintains the system security coordinating for longer period.

An agent between retailers and customers can be called as an Aggregator. A broker may act as an agent between DISCOs and GENCOs. Retail electricity cab be sold by legal approval by retail companies. Electric energy and other services is provided to customers by retailers.

Bilateral Contracts:

It is transmission of power between buying and selling organization

Multilateral Contracts:

Extension of bilateral contract is a multilateral contract. Two or more parties get involved in these contracts. They inject a power in one bus and take out from other bus so that sum of all generations is equal to sum of all loads.

Benefits of multilateral contracts:

Cheaper electricity: It induces to set up more industries and business opportunities in a region thus paving the way for economic growth.Efficient capacity expansion planning: Generating companies will eagerly come forward to set up plants in proper location because of greater knowledge existenceMore choice: Offers will be given by retailers to buy electricity, so customers can have more choices.

Better service: there must be more attention towards better and quality of service and retailers are responsible for it.

Opportunities: due to greater business and industry, investment, employment opportunities are enhanced. The beneficiaries are not only skilled power engineers but also people such as finance personnel, bankers, market traders, etc.

## II. NOTATION

Indexes:

| | |
|---|---|
| $n$ | *No. of buses in total* |
| $n_g$ | *No. of loss supplied by the generators* |
| $n_{tr}$ | *No.of multilateral transactions* |
| $P_{gi}$ | *Generation of active/real power of bus 'i'* |
| $P_{di}$ | *demand of real/active power bus 'i'* |
| $L_i$ | *generator 'i' penalty factor* |
| $QC_i$ | *Quoted cost of loss supplied by the generator 'i'* |
| $PQC_i$ | *Penalized quoted cost of generator 'i'* |
| $P_{loss-ac}$ | *loss function of alternating current* |
| $P_{loss-dc}$ | *loss function of direct current* |
| $L_{ploss}$ | *ac load flow solution real/active power loss in total* |
| $L_k$ | *Transaction loss 'k'* |
| $f_k$ | *contribution fraction of loss of transaction 'k'* |
| $P_i$ | *Injection of net real/active power at bus 'i'* |
| $CT_k$ | *Allocation of cost to transaction 'k'* |
| $TC_{ploss}$ | *cost of loss supplied in total* |
| $B_{mn}$ | *Dc loss coefficients* |
| $B_{ij}\, B_{i0}\, B_{00}$ | *Ac loss coefficients* |

## III. PROBLEM FORMULATION

### 3.1 Bus Admittance Matrix Considering Mutual Inductance:

Through this matrix the effect of mutual inductance is considered. The calculation of this matrix for mutual elements network is presented in (1), (2), (4) which is shown in the equation (1).The matrix calculation with mutually coupled elements is shown in equation (1) to (4). In this method, calculation of this matrix is obtained by addition of mutual elements. This effect causes change in the, nodal voltages, power flowing through the lines, bus admittance matrix thus total network losses. Thus there will be a change in transmission loss and its cost is allocated among the network buses. Loss are shared among buses in penalized quoted cost method. In the load flow solution bus admittance matrix is used.

$$Y_{bus} = A^T y_{prim} A \qquad (1)$$

Where, A- $y_{prim}$ -element node incidence matrix and primitive admittance matrix.

The A,$y_{prim}$ dimensions for a network with 'e' 'n elements and' nodes is (e$\times n$) and (n$\times n$) respectively.

$$y_{prim} = \sum_{i=1}^{e}\sum_{j=1}^{e} y_{prim}^{ij} \qquad (2)$$

Where, $y_{prim}^{ij}$ - (e $\times e$) matrix has one non-zero element only. The non-zero element position is (i,j) and the value is equal to the $y_{prim}$ $(i,j)$value. So equation (1) can be written as

$$Y_{bus} = A^T \sum_{i=1}^{e}\sum_{j=1}^{e} y_{prim}^{ij} A \qquad (3)$$

The $y_{prim}^{ij}$ matrix consists of only one nonzero element as it is a scalar. So the equation (3) can be again written as given in equation (4).

$$Y_{bus} = y_{prim}(i,j) A_i^T A_j \qquad (4)$$

### 3.2 Penalized Quoted Cost (PQC) Method:

Supplying transmission system losses economically under bilateral contract is a challenge for power engineers. Penalized quoted cost (PQC) approach is proposed where generators will participate for supplying the transmission line losses which may be incurred from their customers through their bilateral contracts in a deregulated power market. The loss supplying generators will quote the price and the quantum of active power that can be supplied by them to Independent System Operator (ISO) in a day-ahead market. The proposed PQC based loss allocation approach has the following advantages

- Loss or cost allocation to generators and loads are fair and it is non-negative.
- It uses traditional AC load flow analysis resulting in calculating real power losses.
- Active power loss is shared between generators and loads economically.
- Relative position of the buses is taken into account by considering the penalty factor.
- Losses are allocated to individual transaction considering only the magnitude of real power for a given transaction.
- Independent of size of the system and quantum of generation.
- Understanding and implementation of algorithm is simple.

Let us consider an 'n' number of buses in bus system, 'n_g' loss supplying generators in transmission loss/cost allocation process are included in deregulation market. The penalized quoted cost of the generator 'i' is given by equation (5).

$$PQC_i = L_i \times QC_i \qquad (5)$$

Using loss function derived in Grainger and Stevenson, the penalty factor can be calculated in [6] as given in equation (6).

$$P_{loss-ac} = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{n_g} B_{i0} P_{gi} + B_{00} \quad (6)$$

Change in generation of real power of each generator '*i*', the incremental transmission loss is given as in equation (7).

$$ITL_i = \frac{\partial P_{loss-ac}}{\partial P_{gi}} \quad \text{for } i=1 \text{ to } n_g \quad (7)$$

Then the penalty factor is given by

$$L_i = \frac{1}{1-ITL_i} \quad \text{for } i=1\text{to } n_g \quad (8)$$

Using dc loss function, loss contribution fraction is calculated derived in Fred C. Schweppe et al. in [7] is shown in equation (9).The cost allocation of real power loss is based on loss contribution fraction to the each transaction.

$$P_{loss-dc} = P_i^T [B_{mn}] P_i \quad (9)$$

The real power transaction transmission loss '*k* 'is given in equation (10).

$$L_k = L_{T_{i-j}} = \frac{\partial P_{loss-dc}}{\partial P_i} P_{gi} \sum_{j \in \alpha_k} \frac{\partial P_{loss-dc}}{\partial P_j} P_{dj} \quad (10)$$

Where

$\alpha_k$ – set of load buses for each transaction $k$

Loss contribution fraction is obtained from the transmission loss due to transaction '*k*' and it is given in equation (11). This strategy distributes cost to every transaction in view of based on loss contribution fraction and shares between the generators and loads equally.

$$f_k = \frac{L_k}{\sum_{k=1}^{ntr} L_k} \quad \text{for k=1 to } n_{tr} \quad (11)$$

Cost allocation to each transaction '*k*' is given in equation (12).

$$CT_k = f_k \times TC_{ploss} \quad (12)$$

## IV. CASE STUDY

In this section IEEE-4bus test system is taken to illustrate the proposed technique, which consists of two generators and two loads shown in fig.1.The line, transaction and generator data are presented in below tables respectively. Fuel cost equation of the two generators is assumed as their quoted cost. It is assumed that additional available capacity of each generator for meeting the real power losses is well within the desired value i.e. 4 MW. The mutual inductance value is computed from the reactance value of the line. The two lines average reactance in the data of bus system is computed and 5% of average reactance is assumed as mutual inductance between the lines. The assumed mutual inductance value between the two lines is given in Table 5. The incremental loss cost is 200 $/MWhr

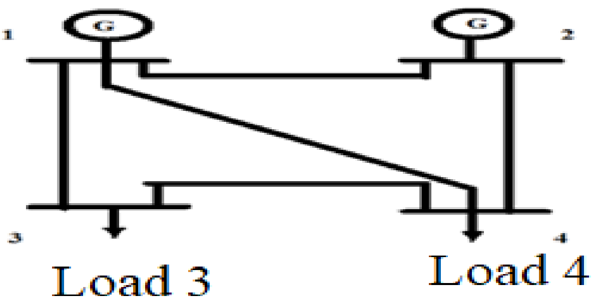


**Fig.1. IEEE-4bus System**

The Fig.1 shows the four bus system. It consists of two load buses and two generator buses at bus 3, bus4 and bus1, bus2 respectively.

**Table 1. Data of each line for IEEE-4bus system**

| From Bus- To Bus | Series Impedance (p.u) | | Shunt Admittance (p.u) |
|---|---|---|---|
| | R (p.u) | X (p.u) | |
| 1-3 | 0.00744 | 0.0372 | 0.0775 |
| 1-2 | 0.01008 | 0.0504 | 0.1025 |
| 4-2 | 0.00744 | 0.0372 | 0.0775 |
| 4-3 | 0.01272 | 0.0636 | 0.1275 |
| 1-4 | 0.00372 | 0.0186 | 0.1550 |

**Table.2. Data of Transaction for IEEE-4bus system**

| Transaction No. | Generator bus no. | Load bus no. | Real Transaction of power (MW) |
|---|---|---|---|
| **1** | **1** | **3** | **182** |
| **2** | **1** | **4** | **100** |
| **3** | **2** | **3** | **38** |
| **4** | **2** | **4** | **180** |

The Table 2 gives the Real power transaction values of a 4-bus system that has obtained.

**Table.3. Data of generator for IEEE-4 bus system**

| Generator bus number. | Generator cost coefficients | | | Quoted cost ($/MWhr) |
|---|---|---|---|---|
| | A | B | C | |
| 1 | 0.0048 | 6.4 | 400 | 406.4 |
| 2 | 0.0040 | 8.0 | 500 | 508 |

The above Table 3 gives the data of a generator cost coefficients and the obtained Quoted cost for the generators.

The transmission real/active power loss acquired from AC load flow solution considering four multilateral transactions by neglecting reactive power demand with the generator placed in the first rank as slack bus is 5.983 MW (refer table 4).

**Table.4. Economic loss allocation schedule**

| Generator Bus no. | Penalty factor | Penalized quoted cost ($/MW hr) | Ranking of generators | Supplied quantity for loss(MW) | Cost of supply of loss($/hr) |
|---|---|---|---|---|---|
| 1 | 1.0311 | 418.83 | 1 | 4 | 1625.6 |
| 2 | 1.0187 | 517.55 | 2 | 1.983 | 1007.4 |
| **Total** | | | | **5.983** | **2633** |

The cost supplying real power loss due to the primary energy transactions in total is 2633 $/hr. This cost has to be allocated for all the four multilateral transactions.

**Table.5. Mutual Inductance Value**

| S. No | Between Lines |
|---|---|
| 1-2, 1-4 | 0.0003 |
| 2-1, 2-4 | 0.0004 |
| 3-1, 3-4 | 0.0005 |
| 4-2, 4-3 | 0.0005 |

**Table.6. Cost Allocation to Individual Transactions**

| Transaction No. | Gen. Bus No. | Real Power P (MW) | Loss contribution fraction | | Allocation of cost ($/hr) | |
|---|---|---|---|---|---|---|
| | | | Without MI | With MI | Without MI | With MI |
| 1 | 1-3 | 182 | 0.3987 | 0.39 | 1049.9 | 1085.8 |
| 2 | 1-4 | 100 | 0.1087 | 0.10 | 286.3 | 296.09 |
| 3 | 2-3 | 38 | 0.1205 | 0.12 | 317.2 | 328.04 |
| 4 | 2-4 | 180 | 0.3720 | 0.3725 | 979.6 | 1013.10 |
| TOTAL | | | 1.0 | 1.0 | 2633 | 2723 |

Active power loss due to each transaction is calculated using equation (11). It is to be noted that the sum of active loss of power due to each transaction is not equal to the loss obtained in AC load flow solution. It is observed that transaction 3 with 38 MW has higher cost allocation compared to transaction 2 because transaction 2 has a direct path from bus 1 to bus 4 whereas there doesn't exist direct path from bus 2 to bus 3.. So, the real power loss which depends on resistance is also high and therefore the allocation of cost to each transaction is also high.

## V.CONCLUSION

The paper discusses about the effect of mutual inductance on transmission line loss/cost allocation for multilateral contracts. Penalty Quoted Cost method is used to demonstrate the results. The results of IEEE-4bus system explains that there is an impact of mutual inductance on transmission loss/cost allocation which it cannot be neglected. In the Results it has been observed that losses and Allocation of cost are increasing if the mutual inductance is considered. Hence the effect of mutual inductance on transmission loss has substantial effect on its cost/loss allocation.

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