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# Assessment of Optimal Multinodal Bilatral Transaction In The Competetive Electricity Market

**Abstract:-** In recent years, the development in the deregulated electricity market structure increases the number of market participants thereby, creates the market more competitive. It is important for the independent power producer (IPP), independent system operator and bulk power customer to know and select the least cost transaction. In this paper, a method for selecting the optimal multi-nodal bilateral transaction for the IPP based on the estimation of maximum allowable load of the buyer buses and on the transaction transmission pricing is proposed. Estimation of maximum allowable load of the buyer buses used to assess the feasibility of each transaction and also help to create profitable and buyer attractable seller price bid. In the context of electricity market, transmission pricing is an important tool to determine the optimal multi-nodal bilateral transaction for the IPP at different seller buses .In this thesis, both embedded cost transmission pricing and incremental cost transmission pricing (short run marginal cost) is considered for the estimation of transaction transmission cost. The proposed method is demonstrated and analyzed for the considered multi-nodal bilateral transaction on 6 bus system and IEEE 30 bus system

## I. INTRODUCTION

### 1.1 General

The electrical utilities are getting restructured in several countries throughout the world, so as to introduce the competition at generation and distribution levels to reduce the cost of energy production and distribution, eliminate certain inefficiencies and increase the customer choice, while retaining the transmission network as natural monopoly for the techno-economic reasons. It is expected to overcome the inefficiencies prevalent in the monopoly franchise structure with assured revenue collection. Apart from the generating companies (Gencos).Transmission companies(Transco), Distribution companies (Discos) and customer, many other entities emerge in the electricity markets, such as Retail companies (Retailcos), System operator (SO), power traders, brokers, scheduling coordinators, etc.

The System operator (SO) is responsible to maintain system security and reliability of power system, apart from ensuring contractual power. It does not own any transmission, generation or distribution facility and has no financial interest in the market. The SO posts the information such as pricing, availability status, transmission constraints, load distribution and line losses and procures ancillary services, coordinate day-ahead scheduling and balancing/regulating services, frequency control ,reactive power/voltage control and reserve services.

Most of the emerging electricity markets have pool as well as bilateral/multilateral transactions. In the pool market model, the pool operator receives electricity transaction bids and offers from suppliers and customers in the power exchange. It settles hourly/half hourly bids. In a bilateral market model, sellers and buyers enter into transactions directly. The quantities traded and the trade prices are at the discretion of these parties and only the amount and points of transactions need to be informed to the System Operator (SO). A multilateral transaction is the generalization of bilateral transactions, where power brokers put together a group of energy producers and buyers to form a balanced transaction.

In a restructured electricity market, the market participants share a common transmission network for wheeling power from the point of generation to the point of consumption. Wheeling is the transmission of electrical energy from a seller to buyer through a transmission network owned by third party. Wheeling of electricity takes place, when a customer purchases electricity from a source other than its own serving utility. The utility whose transmission network is used for wheeling transaction has to be paid for its service and for meeting the losses. Electricity wheeling has become one of the indispensable elements of power system deregulation. Hence it is important to assess the feasible and the least cost transaction for the Independent Power Producer (IPP), to choose the best location for sale of power and also buyer to decide from which IPP they should buy power. In the context of electricity market, transmission pricing is an important tool to achieve an efficient operation of the electricity system. The transmission prices are imposed to recover the cost of wheeling in the power through the transmission system.

In general, the following three pricing schemes are employed for transmission services:

- Embedded cost based pricing: This method is based on recovering, on pro rata basis, the embedded capital cost, average annuals operating cost, replacement cost considering service life and depreciation

- Incremental cost based pricing: This method employs economic load dispatch formulation to compute short run marginal cost (SRMC) and long run marginal cost (LRMC). In case of SRMC, the revenue reconciliation is required to recover capital cost.
- Combination of both two

### 1.2 Objective of the work

The objective of the present work is to find the Optimal Multi-nodal bilateral transaction for the Independent power producer (IPP) injecting Power at different seller buses based on the estimation the maximum allowable load of the buyer buses and on the transaction transmission pricing. The estimation of maximum allowable load of the buyer bus is used for the ISO to find the feasibility of the transaction and also helps to create profitable and buyer attractable seller price bid. The transmission pricing is an important tool to achieve the efficient power system operation and also important to create the price bids for both seller buses and buyer buses. In this thesis, both embedded cost transmission pricing and incremental cost transmission pricing (short run marginal cost) is considered for the estimation of transaction transmission cost. The proposed method has been applied for various bilateral transactions considering maximum allowable load of the buyer bus as the transaction power supplied by IPP on Six bus system and IEEE 30 bus system

### 1.3 Organization of the Thesis

The work carried out in this Thesis has been summarized in seven chapters. The Chapter 1 highlights the brief introduction and the outline of the thesis is also given in this chapter. The Chapter 2 explains the summary of work carried out by various researchers on assessment for feasibility and pricing of wheeling transactions under deregulated environment of power industry. The Chapter 3 briefly describes the Problem formulation involved in this work. The Chapter 4 provides the detail for transmission pricing method used in this work. The Chapter 5 describes the structure of algorithm for solving proposed problem formulation. The Chapter 6 details the results and discussion pertaining to various test cases. The conclusions and future scope are detailed in Chapter 7.

## II. LITERATURE SURVEY

The problem of marginal costs based optimal wheeling rates considering losses, effects of line flow and voltage magnitude constraints has been discussed by Caramanis et al(1986) and Hyde et al Caramanis et al(1989) has described wheeling rate evaluation simulator, which can be used to evaluate the marginal cost of wheeling between utilities, private users and private generators. The principle and the implementation of Mw-mile methodology to evaluate the usage of transmission network capacity for firm transmission services, including wheeling transaction discussed by Dariush et al R. D. Tabors et.al proposed the transmission System Management and methods of transmission Pricing Hamoud et.al proposed the assessment of feasibility in bilateral transactions Yog Raj Sood et.al proposed the selection of best possible wheeling transaction in a deregulated power system has been determined based on available transfer capability and short run marginal cost. Zechun Hu et.al proposed the efficient maximum loading point determination for optimal wheeling transaction

A. Shunmugalath et.al estimate voltage stability and maximum loadability limit (MLL). MLL is the margin between the operating point of the system and the maximum loading point. The optimum cost of generation for MLL of power system is formulated as an optimization problem, which consists of two steps namely computing MLL and the optimum cost of generation for MLL.

S. Venkatesan et.al proposed the a novel method to estimate maximum allowable load at the buyer buses without violating transmission line flow limit for a wheeling transaction in a competitive electricity market. The problem is formulated as a non-linear optimization problem and the application consists of using a developed optimal power flow based on load maximization in each load bus

A Newton-based optimal power flow (OPF) is developed for implementation into a power system simulation environment by T. Nireeksh et.al Kankar Bhattacharya et.al provide the details about Deregulation electricity environment and the various entity of the restructured structure. Hyde M. Merrill, Bruce W.Erickson," Wheeling Rates Based on Marginal Cost Theory", *IEEE Transaction on Power Systems,* Vol 4, No. 4, October 1989, pp1445-1451. R. D. Tabors, "Transmission System Management and Pricing: New Paradigms and International Comparisons," IEEE Transactions on Power Systems, Vol. 9, No. 1, February 1994, pp. 206-215. Federal Energy Regulatory Commission of the United States of America, "Promoting wholesale competition through open access non-discriminatory transmission services by public utilities," Docket No. RM95-8-00, March 1995.759-765. Hamoud G. Feasibility assessment of simultaneous bilateral transaction in a deregulated environment. IEEE Transaction Power System, 2000; 15(1):pp.22–6. Yog Raj Sood, Narayana Prasad Padhy and H.O. Gupta, "Wheeling of Power Under Deregulated Environment of Power

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## III. HOW RESTRUCTURING ASSISTS LIBERALISATION OF ELECTRICITY MARKETS.

### 3.1. Introduction

### 3.1.1 Liberalisation in the electricity sector

Electricity sector liberalisation - the introduction of competition, the reduction of external, especially political, interference, the opening up of markets to new players - is a world-wide phenomenon. Although only a handful of countries have yet to achieve what might be considered significant liberalisation, few countries anywhere in the world have been able to ignore domestic and international pressure for reform and for radical change. The motives for liberalisation are various and stem from many sources. This paper will not consider these motives in any detail but it is the belief of the authors that pressure for liberalisation will remain one of the most significant forces in global electricity markets well into the next millennium.

Economic liberalisation (and, often, the political liberalisation that may accompany it) is a significant challenge. It not only involves "hard" reform and restructuring but also demands "softer" changes in attitudes and ways of thinking. Amongst all significant economic sectors, liberalisation of the electricity industry is, perhaps, uniquely challenging. The physical characteristics of electricity supply, the place of the industry close to industrial policy decision-making and (in many cases) public finances, the close and complex relationships between the electricity industry and other significant elements of the economy, the size of the industry and the magnitude of its capital requirements all conspire to complicate and to make more difficult the process of liberalisation.

### 3.1.2 Objectives of this paper

No matter in what "pre-liberalisation position" a country finds itself, some industry restructuring will be inevitable if liberalisation is to be achieved. A series of restructuring options is available: the choices made can be the key to its success. This paper undertakes an analysis of certain liberalised and liberalising electricity markets, placing particular emphasis on industry restructuring.

This paper considers for seven countries (or groups of countries):

- the economic and political circumstances within which the liberalisation process has been initiated and progress made;
- the resulting demands placed on restructuring within the liberalisation process;
- the restructuring options open and choices made; and
- the practical lessons emerging to date.

The countries chosen are the liberalised markets in Argentina, the Nordic countries and the United Kingdom and the liberalising markets in Brazil, Hungary, India and the United States.

### 3.1.3 Electricity industry restructuring: basic principles

At its most simple, electricity industry restructuring normally comprises two stages. The first is managing the "unbundling" (be it functional or legal) of existing vertically integrated operations into the constituent elements of the industry (generation, transmission, distribution and supply - in some instances distribution and supply are taken as a single operation), so that competitive forces can be introduced into the generation and supply businesses. The second is taking decisions as to the new structure of the separate sectors. Figure 1 sets out the possible relationships between the various elements of a liberalised and restructured electricity supply industry.

## IV. PROBLEM FORMULATION

### 4.1 Optimal power flow based SRMC

### 4. 1.1 Optimal power flow

OPF seeks to optimize steady state power system performance with respect to an objective while satisfying various constraints. The algorithm developed in this paper is based on gradient method of OPF. The objective function is to minimize C; which is summation of functions $F_i\left(P_{gi}\right)$: Under deregulated environment, this function $F_i$ for any generator bus i represent the asking price or bid (in $ for a given MWh) that the generation owner is presenting to a power pool or ISO

$C = \sum_{i=1}^{Ng} F_i\left(P_{Gi}\right)$ $/h

(4.1)

Where

$F_i\left(P_{Gi}\right)$ is the fuel cost function of generator unit i

$P_{Gi}$ = power generation by the $i^{th}$ generator
$N_G$ = number of generator participating in power pool
Subject to set of system constraints as given below

**(a) Equality constraints**

These include real and reactive power balance equations at each node and the bilateral transaction power balance, which can be written as,

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} V_i V_j \left(G_{ij} cos\delta_{ij} + B_{ij} sin\delta_{ij}\right) = 0 \qquad (4.2)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} V_i V_j \left(G_{ij} sin\delta_{ij} - B_{ij} cos\delta_{ij}\right) = 0 \qquad (4.3)$$

$$P_{Gp} - P_{Dq} = 0 \qquad (4.4)$$

Where

$P_{Gi}$ = real power generation at bus-i,
$Q_{Gi}$ = Reactive power generation at bus-i
$P_{Di}$ = Real power load at bus-i
$Q_{Di}$ = Reactive power load at bus-i
$n$ = number of buses in the system
$V_i$ = Voltage magnitude at bus-i
$Y_{ij} = G_{ij} + jB_{ij} = ij^{th}$ element of bus admittance matrix
$\delta_{ij}$ = Voltage angle difference between bus i and bus j

**(b) Inequality constraints**

These include system operating limits as given below

**Voltage limit:** These include the upper and lower limit on the bus voltage magnitude at all the buses

$$V_{imin} \leq V_i \leq V_{imin}, i \in N, \qquad (4.5)$$

**Real and reactive power generation limit:** These represents' the maximum and minimum limit on the real and reactive power output of the generators

$$P_{Gimin} \leq P_{Gi} \leq P_{Gimax}, i \in N_G, \qquad (4.6)$$

$$Q_{Gimin} \leq Q_{Gi} \leq Q_{Gimax}, i \in N_G, \qquad (4.7)$$

**Line flow limit:** This constraint represents that the power flow in any line must be within its maximum permissible limit

$$|P_{ij}| \leq P_{ijmax}, ij \in N_l, \qquad (4.8)$$

Where

$P_{ijmax}$ = Maximum limit on power flow in a line connected between bus i and bus j
$P_{ij}$ = Power flow in a line connected between bus i and bus j

### 4.1.1 Short run marginal cost of wheeling transaction

The SRMC for one unit of bilateral multi-nodal wheeling transactions between the seller buses (IPP) and buyer is determined as the difference in bus incremental cost at n seller buses and buyer buses k. The incremental cost (marginal cost of the real power) to deliver power at a bus is called bus incremental cost (BIC) and plays a very important role in the operation of deregulated power system

$$\text{SRMC} = \sum_{i=1}^{n} \text{BIC at bus i} * ts_i - \text{BIC at bus j} \qquad (4.9)$$

BIC is determined from OPF program, which is formulated above. $Ts_i$ is the transaction Share ratio of total load shared by the seller buses. SRMC include the cost of incremental transmission losses and effect of congestion in transmission system. Fixed cost corresponding to allocation of embedded cost of transmission may also be added to SRMC. When SRMC is negative, than seller has to pay only its share of fixed cost.

### 4.2 Maximum allowable load problem Formulation

Maximum allowable load with respect to the bilateral transaction can be calculated by increasing the IPP generation at the seller bus and simultaneously, the loads by the same amount at the buyer buses, until the power system reaches one of the system limits. The estimation of maximum allowable load can be formulated as an optimization problem with an objective to maximize a scalar loading parameter λ for selected transactions

The objective functions is to determine the maximum allowable load for the bilateral transaction, can be formulated as to

$$\text{Maximize } \lambda \qquad (4.10)$$

Subject to set of system constraints as given below

**(a) Equality constraints**

These include real and reactive power balance equations at each node and the bilateral transaction power balance, which can be written as,

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} V_i\, V_j \left(G_{ij}\, cos\delta_{ij} + B_{ij}\, sin\delta_{ij}\right) = 0 \tag{4.11}$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} V_i\, V_j \left(G_{ij}\, sin\delta_{ij} - B_{ij}\, cos\delta_{ij}\right) = 0 \tag{4.12}$$

$$P_{Gp} - P_{Dq} = 0 \tag{4.13}$$

Where

$P_{Gi}$ = real power generation at bus-i

$Q_{Gi}$ = Reactive power generation at bus-i

$P_{Di}$ = Real power load at bus-i

$Q_{Di}$ = Reactive power load at bus-i

$n$ = number of buses in the system

$V_i$ = Voltage magnitude at bus-i

$Y_{ij} = G_{ij} + jB_{ij} = ij^{th}$ element of bus admittance matrix

$\delta_{ij}$ = Voltage angle difference between bus I and bus j

**(b) Inequality constraints**

These include system operating limits as given below

**Voltage limit:** These include the upper and lower limit on the bus voltage magnitude at all the buses

$$V_{imin} \leq V_i \leq V_{imin}\,,\ i \in N_, \tag{4.14}$$

**Real and reactive power generation limit:** These represents' the maximum and minimum limit on the real and reactive power output of the generators

$$P_{Gimin} \leq P_{Gi} \leq P_{Gimax}\ ,\ i \in N_{G,} \tag{4.15}$$

$$Q_{Gimin} \leq Q_{Gi} \leq Q_{Gimax}\ ,\ i \in N_{G,} \tag{4.16}$$

**Line flow limit:** This constraint represents that the power flow in any line must be within its maximum permissible limit

$$|P_{ij}| \leq P_{ijmax}\ ,\ ij \in N_{l,} \tag{4.17}$$

Where

$P_{ijmax}$ = Maximum limit on power flow in a line connected between bus i and bus j

$P_{ij}$ = Power flow in a line connected between bus i and bus j

In equations. (3.11) and (3.12), $P_{Gi}$ and $P_{Di}$ have been changed in the following manner

Pgi = P ^0 gi * $(1 + Y)$*Tgi, i € s (4.18)

$$P_{Di} = P^0{}_{Di} * (1 + \lambda)\,,\quad i \in N_{b,} \tag{4.19}$$

Where $P^0{}_{Gi}$ and $P^0{}_{Di}$ are the base case real power generation and load values at bus i, $N_s$ *and* $N_b$ represents the seller buses at which IPP is connected and buyer bus. $T_{sGi}$ is the transaction Share ratio of total load shared by the seller buses .Here $\lambda = 0$ corresponds to no additional load (base case) and $\lambda = \lambda_{max}$ corresponds to the maximum allowable loading factor The Maximum allowable load, in each case are calculated as following

Maximum allowable load $= P^0{}_{Di} * (\lambda_{max})$ (4.20)

The above maximum allowable load problem formulation for the bilateral transaction by IPP is solved using Repeated Power flow method. This maximum allowable load determination is used to assess the feasibility of each transaction and also it helps the seller to create buyer attractable and profitable price bids.

### 4.3 Modeling of Multi-nodal /Multilateral contracts in bilateral electricity Trades

The conceptual model of bilateral dispatch is that sellers (Gencos) and buyers (Disco or Direct customers) can directly enter into transactions where the quantities traded and the associates prices are at the discretion of these parties and not a matter of system operator. The bilateral concept can be generalized to the multi-nodal case where seller, for example a generation, may inject power at several nodes and the buyer also draw load at several nodes. Mathematically, a multi-nodal bilateral contract- k involving more than one Point of power injection and or one more than one Point of power injection can be expressed as

$$\sum_m P^k{}_{Gm} - \sum_n P^k{}_{Dn} = 0\ , k=1, 2\ldots\ldots t_k \tag{4.21}$$

Where, $P_{Gm}$ and $P_{Dn}$ stand for the power injections into the seller bus-*m* and the power taken out at the buyer bus-*n*, respectively, and $t_k$ is the total number of the Multi-nodal Bilateral contracts.

## V. PRICING SCHEMES

### 5.1 Pricing Schemes

In general, the following three pricing schemes are employed for transmission services:

- Embedded cost based pricing: This method is based on recovering, on pro rata basis, the embedded capital cost, average annuals operating cost, replacement cost considering service life and depreciation

- Incremental cost based pricing: This method employs economic load dispatch formulation to compute short run marginal cost (SRMC) and long run marginal cost (LRMC). In case of SRMC, the revenue reconciliation is required to recover capital cost.
- Combination of both two

In this thesis, the transmission pricing is an important tool to determine the optimal bilateral transaction by the IPP. Both embedded cost based pricing and Incremental cost based pricing is considered to find the best location for the sale of power by IPP. The incremental cost based pricing is computed using SRMC. This SRMC is obtained from the optimum power flow. The Embedded cost pricing is computed using MW-Mile Method. Embedded cost based on MW-Mile Method provides a measure of how much each transaction uses the transmission system, and the price is proportional to the transmission usage by respective transactions. The power flow miles of each transmission line are totaled up to represent the amount of the transmission resources used by the corresponding transaction. All the line lengths are assumed to be 100 miles and the Transmission cost is taken to be 50$/MW-Mile-annum.

## VI. RESULTS AND DISCUSSION

**6.1 Test Systems**

**6.1.1 Six bus System**

**6.1.2 IEEE Thirty bus System**

### 6.1 Test systems

The proposed method is demonstrated on the 6 bus system and IEEE 30 bus system to determine the optimal bilateral multi-nodal transaction for the IPP at different seller buses with the equal transaction share of load. For this present study, the reactive power demand at load bus has been taken as constant. For both the test systems, the results are obtained by the following approaches

- Determine the optimal generation patterns and marginal cost of the real power at the buyer bus using Optimal Power Flow
- Estimating the Maximum allowable load of the buyer bus using Repeated Power flow with optimal setting of generators obtained from OPF
- Estimation of SRMC, Embedded cost based on Mw-Mile method and Generation cost by considering Maximum allowable load as a transaction power
- Optimal bilateral multi-nodal transaction for the considered IPP at different seller buses

The total transmission system cost is then the sum of Embedded cost and the SRMC, When SRMC is negative, than seller has to pay only its share of fixed cost (Embedded cost).Embedded cost based on MW-Mile Method provides a measure of how much each transaction uses the transmission system, and the price is proportional to the transmission usage by respective transactions. The power flow miles of each transmission line are totaled up to represent the amount of the transmission resources used by the corresponding transaction. All the line lengths are assumed to be 100 miles and the Transmission cost is taken to be 50$/MW-Mile-annum.

## VII. CONCLUSIONS

**7.1 Conclusions**

**7.2 Scope for further work**

### 7.1 Conclusions

The Proposed method for determining optimal Muti-nodal bilateral transaction for the IPP was tested on 6-bus test system and IEEE 30-bus test system by estimating the Maximum allowable load of the buyer buses supplied by IPP at different seller buses and estimating the total transaction cost for various transactions supplied by IPP. The optimal multimodal bilateral transaction for the IPP at the seller buses will be the minimized total transaction cost at the load bus. This assessment of optimal multinodal bilateral transaction provide following conclusions

- The Estimation of maximum allowable load of the buyer buses provides the Available transfer capability information for each multimodal bilateral transaction between IPP and the buyer bus without violating the security limits of the system and this information is very much needed for system operator to check the feasibility for further transactions
- The maximum real power generation at any bus in a system is known from the maximum allowable load of the buyer buses calculation. The maximum real load for particular bus, which can be supplied from any bus of the system, is also known. These information will be great helpful for the IPP, bulk power consumers as well as for ISO to utilize their full capability for various transactions.
- The total transaction cost determination helps the IPP at different buses to choose the best location for selling their power and also the information will helps to create the profitable and buyer attractable price bid.

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### 7.2 Scope for further work

This thesis gives the solution for finding the best location for IPP at various seller buses to sell their power at single bus. This can be also used for the IPP to find the best load buses to sell their power for multilateral transaction and also for the market operator to decide their optimal multilateral contract.

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