Power Flow Based Contract Path Method for Transmission Pricing

I. Kranthi Kiran, A. Jaya Laxmi

***Abstract* — Provision of correct economic signals to the market participants like generation companies, wheeling companies and customers in a deregulated electricity market is necessary. The operation of the wheeling company between generation companies and customers must ensure reliable and secured operation of the overall power system. Proper wheeling cost methodology is needed to allocate the cost of transmission transactions to the customers to achieve it. Accurate transmission pricing scheme still remains a challenging task. This paper gives an overview of different cost components of wheeling party, principles of wheeling pricing and a detailed presentation of a power flow tracing methodology and 'embedded' wheeling cost methodology namely 'Contract path method'. This method is applied to an application example illustrated to calculate the wheeling cost and the results obtained are illustrated.**

Index Terms — **Contract path, Embedded cost, Wheeling, Wheeling cost**

I. INTRODUCTION

The rapid fluctuations in the trade environment all around the world has resulted in unbundling of services provided by vertically integrated electric power utilities [1]. The restructuring of electric power industry focused the price of electricity in all activities of the power market. In the transmission activity of the electric power system operation, the pricing policy is such as to recover all or part of both existing and new costs of the transmission system. Wheeling cost determines the economic feasibility to both wheeling utility and wheeling customers [2]. So, it is important to allocate transmission costs among all customers so as to recover different costs of the transmission system as well as to provide smooth operation of the power system [3].

II. WHEELING PARTY'S COST COMPONENTS

The principal goal of any wheeling cost calculation method is the recovery of costs of transmission assets [4]. Different cost components of the wheeling party include capital cost, operational and maintenance costs, cost of network losses and congestion cost.

A. Capital cost

The capital cost includes the one-time setup cost associated with the network, including the price of purchased assets such as land, equipment, or other supplies, and the cost of debt or stock issued in order to fund the project.

For capital cost recovery, historical cost approaches like embedded wheeling cost methodologies depend exclusively upon the calculation of the annuitized cost of assets of the network [5]. Consequently, the recovered cost is based on the assessment of the cost of the existing network, from an asset valuation. These approaches are good at recovering actual system costs, although there are tradeoffs in the extent to which historical costs are considered to be economically efficient [6].

B. Operational and Maintenance costs

The operational and maintenance costs include the ongoing and repetitive costs of operating and maintaining a system.

For the system as a whole, the operational and maintenance costs of each asset are most readily recovered by allowing a predetermined margin typically in the range 2-5% of the capital cost of the equipment to cover an appropriate amount on an annual basis [7]. It needs to be sufficient in covering the costs of operating the centralized control functions within the transmission operator business, as well as in maintaining the requirements of the individual assets themselves.

C. Cost of Network losses

The cost of transmission losses can be included in the costs recovered by the wheeling pricing methodology [8].

Many international market models leave the allocation of losses for the electricity market to resolve, through the adjustment of metered quantities in the settlement process. Cost of losses can be recovered by allocating the overall cost of losses across all system users or by identifying the costs arising from the incremental of losses with the impact of specific wheeling trades on the network [9]. A key consideration is the route by which the cost of losses are recovered, and how the transmission operator is incentivized to reduce the losses.

D. Congestion cost

The cost of congestion is the change in bid production costs resulted from the transmission congestion [10].

Transmission congestion has several principal impacts on the system operation and as such needs to be considered carefully in terms of its treatment in relation to wheeling. It can affect the dispatch of generation, can demand new procedures for giving access to transmission circuits for specific transactions, including the management of "Available Transmission Capacity" and can even lead to the separation of an electricity market into different physical zones for the purpose of defining market prices [11].

The presence of congestion can be signaled simply in transmission pricing by allowing charges for the use of specific lines to vary depending on whether the flow created by a given transaction increases or decreases the prevailing flow on the line.

Manuscript received January 15, 2014.

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Under a more dynamic approach, the possible existence of congestion is predicted and managed through the splitting of a market into zones, or even nodes, at which separate prices are calculated. The ability to do this depends on the sophistication of the electricity market and the existence of some form of short-term market in which the costs of electricity are time varying.

III. 'WHEELING PRICING' PRINCIPLES

The essential regulatory principles required by any wheeling cost computation method in crafting a fair framework promoting competition in the electricity market are as follows:

A. Ensuring fairness, transparency and predictability

Ideally the methodology should be easy to understand, should be able to transmit right economic signals to market participants and stable in long-term, avoiding "price shocks" [12]. This requires an authority system to stimulate confidence in regulatory framework and inspire new market participants.

B. Recovering and meeting costs, gaining profits

The methodology should be adequate to recover full or part of the investments, should be able to meet operational and maintenance costs and should gain some profit. However cost recovery is mandatory to maintain the assets. Different methodologies such as historic cost methodologies and forward looking methodologies like short-run marginal cost methodologies and long-run incremental cost methodologies can be applied for cost recovery. Full recovery of cost is possible by the former but there is no guarantee of it with late one.

C. Promoting efficient usage

This is achieved by giving incentives to the network users dealing with minimum transmission power losses to promote competition.

D. Encouraging investment

This is achieved by giving incentives to the network owners to promote competition for investment in new infrastructure whenever needed.

E. Promoting non-discriminatory behaviour

It involves treating equally the network users having the same impact in order to ensure the allocation of recovery of any residual costs (where price signals do not recover the full costs) in a fair way.

IV. POWER FLOW TRACING METHODOLOGY

A. Bialek's tracing method

Bialek's tracing method uses either the upstream looking algorithm or the downstream looking algorithm, to determine the contribution of individual generators based on the calculation of topological distribution factors [13]. In the former case, the wheeling charge is allocated to individual generators and losses are distributed to individual loads and vice-versa in latter case.

The Bialek's tracing procedure:

B = (mxn) sized matrix called 'Incidence matrix' with its elements value equal to 1 when power flows from 'm' bus to 'n' bus, -1 when power flows from 'n' bus to 'm' bus and 0 when no power flows between 'm' bus and 'n' bus.

B_d = (mxn) sized matrix derived from incidence matrix, consisting of 1's and other element values equal to zero.

B_u = (mxn) sized matrix derived from incidence matrix, consisting of -1's and other element values equal to zero.

$$F_d = -B_d^T.\mathrm{diag}(F).B_u \tag{1}$$

$$A_d = I + B_d^T.\mathrm{diag}(F).B_u.\mathrm{diag}(P^{-1}) \tag{2}$$

$$A_u = I + B_u^T.\mathrm{diag}(F).B_d.\mathrm{diag}(P^{-1}) \tag{3}$$

Equation (1) results in an (nxn) sized matrix with the (i, j) element indicating line flow from ith bus to jth bus. Equations (2) and (3) provide two non-singular matrices, each of size (nxn).

$$P_{G_{ki}} = \frac{P_{D_i}.P_{G_k}.[A_u^{-1}]_{ik}}{P_i} \tag{4}$$

$$P_{G_{kj}} = \frac{F_{D_j}.P_{G_k}.[A_u^{-1}]_{ik}}{P_i} \tag{5}$$

Equation (4) can be used to find the kth generator's active power contribution to ith bus active load whereas equation (5) to determine kth generator's active line power flow contribution to jth line's active line flow. The same equations can be dealt with reactive loads and other types of powers also [14]. Thus these two equations can be used to determine the transmission network usage due to individual generators and individual loads.

V. CONTRACT PATH METHOD

In this methodology a specific path called the 'contract path' between the points of delivery and receipt is selected by both utility company and wheeling customer [15]. The path selection for a wheeling transaction is carried out usually without performing a power flow study to identify the actual transmission facilities involved in the transaction. A share or full of the asset costs, including the costs of new investment, along the contract path is allocated to the wheeling customers in proportion to their usage [16].

The transmission facilities existing outside the contracted path and/or the neighboring utilities' transmission systems may carry the majority of the transacted power and hence may lead to investments being necessary in areas of the system which are not on the contract path at all [17]. Since the cost of such upgrades may not be included in the wheeling cost, wheeling customers receive incorrect economic signals and uneconomic transactions may take place. Thus the usage of contract path approach for wheeling cost calculation is potentially discriminate between users and is economically inefficient.

A. Advantages

Full cost recovery is possible as costs of both existing assets and new assets along the contract path are considered. It benefits investors and encourages for an efficient level of investment.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The system creates a simple and stable pricing rule, and is easy to implement [18].

Relative to the postage stamp methodology, the contract path approach provides an improved ability to signal the costs of decisions by individual users.

VI. APPLICATION EXAMPLE

A six-bus eleven-line system shown in Fig.1 is considered for the effect of contract path on the wheeling cost of each generator [19]. The bus data, generator data and the line data of the bus system considered are presented in Tables numbered 1, 2 and 3 respectively (Appendix).

The wheeling cost is calculated by contract path method, with buyers at buses-4, 5 and 6 demanding same power from a group of sellers available at buses-1, 2 and 3 with the generators at these buses having same reactive power generation limits of -150 MVAr and 150 MVAr respectively.

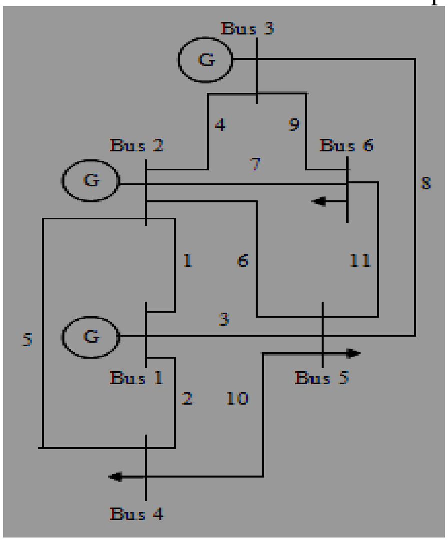

Fig.1 Six-bus, eleven-line bus system

Table 4 shows the line power flows and line losses. Tables 5 and 6 present the contribution of each generator to the bus power demands including line power losses and line power flows.

Table 4. Line power flows and line losses

Line no.	P_pq	Q_pq	P_qp	Q_qp	P_L	Q_L
1	29.12	-14.50	-28.19	14.16	0.93	-0.34
2	43.70	22.73	-42.57	-20.31	1.12	2.42
3	35.63	14.89	-34.51	-13.78	1.12	1.11
4	2.98	-10.63	-2.94	7.46	0.04	-3.17
5	33.28	49.60	-31.64	-47.35	1.64	2.25
6	15.50	18.47	-14.93	-18.84	0.57	-0.37
7	26.43	15.27	-25.81	-16.13	0.62	-0.86
8	19.33	26.88	-18.10	-26.84	1.23	0.04
9	43.62	64.50	-42.55	-60.21	1.07	4.29
10	4.21	-2.34	-4.17	-1.45	0.04	-3.79
11	1.71	-9.10	-1.65	6.34	0.06	-2.75

Table 5. Generator-wise contribution to bus-wise power demands including line power losses

PV bus no.	Active power demand contribution			Reactive power demand contribution		
	Bus-4	Bus-5	Bus-6	Bus-4	Bus-5	Bus-6
1	52.90	43.85	11.68	13.77	9.34	0.00
2	20.07	11.42	18.50	51.33	23.05	12.47
3	0.00	17.98	42.01	3.72	34.89	60.21

Table 6. Generator-wise contribution to line power flows

Line no.	Active power flows (MW)					
	PV bus-1	PV bus-2	PV bus-3	PV bus-1	PV bus-2	PV bus-3
1	29.11	0.00	0.00	0.00	12.61	1.08
2	43.69	0.00	0.00	13.96	7.62	0.65
3	35.63	0.00	0.00	9.15	4.99	0.42
4	1.11	1.90	0.00	0.00	0.00	7.45
5	12.39	21.28	0.00	0.00	44.19	3.79
6	5.77	9.90	0.00	0.00	16.45	1.41
7	9.84	16.90	0.00	0.00	13.60	1.16
8	0.34	0.58	18.42	0.00	0.00	26.87
9	0.77	1.32	41.57	0.00	0.00	64.49
10	3.18	1.20	0.00	-0.19	-0.47	-0.72
11	1.07	0.27	0.43	0.00	1.13	5.45

VII. CONCLUSION

If the buyer or customer of electricity receives all the demanded power from the seller or generator of electricity of opted choice through the electrical path contracted between both, then the 'contract path' methodology can be used to determine the wheeling cost for power trading between the seller and buyer. However, there is no guarantee that the power transfer takes place through the contracted electrical path only and so the afore-mentioned methodology ignores the actual path of the power flow that would occur.

Table 7 presents the generator-wise wheeling costs determined by contract path methodology for bus-wise loads. Table 8 presents the same with all lines assumed to be in the contract.

Table 7. Generator-wise wheeling costs under different contract paths

Load bus no.	Generator bus-1		Generator bus-2		Generator bus-3	
	'Contract path' line no.s	Wheeling cost (Rs.)	'Contract path' line no.s	Wheeling cost (Rs.)	'Contract path' line no.s	Wheeling cost (Rs.)
4	1, 2, 3, 5, 10	54,387	1, 2, 3, 5, 6, 10	38,582	2, 3, 8, 10	23,836
5	1, 2, 3, 6, 10	54,141	1, 3, 6, 7, 11	30,164	8, 9, 11	34,678

6	1, 3, 6, 7, 11	41,804	4, 6, 7, 9, 11	21,268	4, 7, 8, 9, 11	37,306

Table 8. Generator-wise wheeling costs under a single contract path

Load bus no.	Generator bus-1		Generator bus-2		Generator bus-3	
	'Active' line no.s	Wheeling cost (Rs.)	'Active' line no.s	Wheeling cost (Rs.)	'Active' line no.s	Wheeling cost (Rs.)
4	1 to 11	62975	1 to 11	49154	1 to 11	41068
5						
6						

NOMENCLATURE

no. - number
p.u. - per unit
V - Bus voltage magnitude in p.u.
δ - Bus voltage phase angle in degrees.
V_l & V_u - Lower and upper limits of V in p.u.
P_d & Q_d - Demanded active and reactive powers in MW and MVAr respectively.
P_g & Q_g - Generated active and reactive powers in MW and MVAr respectively.
P_l & P_u - Lower and upper limits of Pg in MW.
γ, β and α - Generator fuel cost coefficients in Rs./MW^2, Rs./MW and Rs. respectively.
p & q - Sending-end and receiving-end bus no.s.
R - Line resistance in p.u.
X - Line inductive reactance in p.u.
B - Half total line charging susceptance in p.u.
l - Line length in km.
P_pq & P_qp - Active power flow from pth bus to qth bus and vice versa in MW.
Q_pq & Q_qp - Reactive power flow from pth bus to qth bus and vice versa in MVAr.
P_L & Q_L - Active and reactive power losses in MW and MVAr respectively.
Rs. - Rupees

APPENDIX

Table 1 : Bus data

Bus no.	Bus type	V	δ	V_l	V_u	P_d	Q_d
1	Slack	1.05	0	0.94	1.06	0	0
2	PV	1.05	0	0.94	1.06	0	0
3	PV	1.07	0	0.94	1.06	0	0
4	PQ	1.00	0	0.94	1.06	70	70
5	PQ	1.00	0	0.94	1.06	70	70
6	PQ	1.00	0	0.94	1.06	70	70

Table 2 : Generator data

PV bus no.	P_g	P_l	P_u	Q_g	γ	β	α
1	0	10	85	0	0.008	7.0	200
2	50	10	80	0	0.009	6.3	180
3	60	10	70	0	0.007	6.8	140

Table 3 : Line data

Line no.	p	q	R	X	B	l
1	1	2	0.10	0.20	0.020	578
2	1	4	0.05	0.20	0.020	289
3	1	5	0.08	0.30	0.030	463
4	2	3	0.05	0.25	0.030	289
5	2	4	0.05	0.10	0.010	289
6	2	5	0.10	0.30	0.020	578
7	2	6	0.07	0.20	0.025	405
8	3	5	0.12	0.26	0.025	694
9	3	6	0.02	0.10	0.010	116
10	4	5	0.20	0.40	0.040	1156
11	5	6	0.10	0.30	0.030	578

REFERENCES

1. Z. Yu, D. GachiriNderitu and F. T. Sparrow, "A proposed market power monitoring model for restructuring electricity markets", IEEE Power Engineering Review, July 2000, *pp. 41–42*.
2. R. D. Christie, B. F. Wollenberg and I. Wangensteen, "Transmission management in the deregulated environment", Proc. of IEEE, Vol. 88, Feb. 2000, *pp. 170–195*.
3. Mohammad Shahidehpour, HatimYamin and Zuyi Li, "Market
4. Operations in Electric Power Systems: Forecasting, Scheduling, and Management" , First Edition, John Wiley and Sons Limited, 2002,pp: 1 –20, 57 – 113 and 115– 160.
5. H.H.Happ," Selection of methods for evaluating the cost of transmission wheeling services", Proc. of the American Power Conference, 57th Annual Meeting, Technology for a Competitive World, Vol. 1, Chicago, IL, Apr. 18–20, 1995, *pp. 606–611*.
6. J. W. M. Lima, M. V. F. Pereira and J. L. R. Pereira, "An integrated framework for cost allocation in a multi-owned transmission system", IEEE Transactions on Power Systems, Vol. 10, May 1995, *pp. 971–977*.
7. Sally Hunt and Graham Shuttleworth, "Competition and Choice in Electricity", First Edition, John Wiley and Sons Limited, 1996,pp: 9 – 52 and 181 – 204.
8. A. F. Vojdani, C. F. Imparato, N. K. Saini and H. H. Happ, "Transmission access issues", IEEE Transactions on Power Systems, Vol. 11, Feb. 1996, *pp. 41–51*.
9. Lewis P., "Wheeling and Dealing [Power Transmission]", IEE Review, Vol.42, Issue 5, September 1996, pp.196-198.
10. F. D. Galiana and M. Phelan, "Allocation of transmission losses to bilateral contracts in a competitive environment", IEEE Transactions on Power Systems, Vol. 15, Feb. 2000, *pp. 143–150*.
11. Loi Lei Lai, "Power System Restructuring and Deregulation: Trading, Performance and Information Technology", First Edition, John Wiley and Sons Limited, 2002,pp:50 – 75 and 172 – 193.
12. BaranMesut E., Banunarayanan, Garren Kenneth E., "Equitable Allocation of Congestion Relief Cost to Transactions", IEEE Transactions on Power Systems, Vol.15, No.2, May 2000, pp.579-585.
13. Billinton R., Wang P., "Deregulated Power System Planning using a Reliability network Equivalent Technique", IEE Proc.-Generation Transmission Distribution, Vol.146, No.1, January 1999, pp.25-30.

14. A. Fradi, S. Brignone and B. F. Wollenberg, "Calculation of energy transaction factors", IEEE Transactions on Power Systems, Vol. 16, May 2001,*pp. 266–272*.
15. G. Strbac, D. Kirschen and D. Ahmed, "Allocating transmission system usage on the basis of traceable contributions of generators and loads to flow", IEEE Transactions on Power Systems, Vol. 13, May 1998, *pp. 527–534*.
16. J. Pan, Y. Teklu, and S. Rahman, "Review of usage-based transmission cost allocation methods under open access", IEEE Transactions on Power Systems, Vol. 15, Nov. 2000, *pp. 1218–1224*.
17. M. L. Baughman, S. N. Siddiqi and J. W. Zarnikau, "Advanced pricing in electricity systems", IEEE Transactions on Power Systems, Vol. 12, Feb. 1997, *pp. 489–502*.
18. Torre Teofio De La , Feltes James W., Roman Tomas Gomez San , Merrill Hyde M., "Deregulation, Privatization and Competition: Transmission Planning under Uncertainty", IEEE Transactions on Power Systems, Vol.14, No.2, May 1999, pp.460-465.
19. Kankar Bhattacharya, Math H.J. Bollen and Jaap E. Daalder, "Operation of Restructured Power Systems", First Edition, Kluwer Academic Publishers, 2001, pp: 1 – 72 and 119 – 169.
20. Allen J. Wood and Bruce F. Wollenberg, "Power Generation, Operation, and Control", Second Edition, Wiley India Private Limited, 2006, pp: 29 – 170 and 363 – 409.

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