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Transmission Pricing in Restructured Power System Using Power Tracing

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ABSTRACT

This paper presents a study of determining transmission pricing by usage allocation to generators using Bialek's tracing method. Bialek's tracing algorithm has been applied on 5 bus test system. Transmission prices are calculated using power flow tracing based MW-mile method for 5 bus test system.

KEYWORDS: Power flow tracing, Usage allocation, Transmission pricing, Proportional sharing principle

I. Introduction

Generation, transmission and distribution are three basic components of electrical power industry. Transmission system provides vital link between generation and distribution. Power industry is passing through era of drastic change in its structure and operation. Earlier vertically integrated power system is now converted to deregulated industry in which generation, transmission and distribution are now separate entities [1]. In deregulated power system energy trading take place through pool market or bilateral contracts or power exchange. While the former vertically integrated utility charged one price for power delivery, today every single service has to be priced separately.

Transmission system should provide equal access to all generators and loads without any discrimination to promote fair competition. Due to high capital cost and certain security issues, transmission is natural monopoly industry. The objective of transmission pricing is to recover all or part of existing and new cost of transmission system. Open access customers use electrical 'highway' hence they should pay toll in form of transmission price. The electricity tracing method would make it possible to charge the generators or consumers on the basis of actual transmission facility used.

II. transmission pricing methods

Mainly three types of pricing paradigms are considered: Rolled in, Marginal and Composite.

Methods in rolled in pricing paradigms are [7]:

1. Postage stamp method
2. Incremental postage stamp method
3. Contract path method
4. Distance based MW-mile method
5. MVA mile method
6. Counter flow method
7. Distribution factor method
8. Point of connection tariff

Postage stamp method[8]:

Postage-stamp rate method is traditionally used by electric utilities to allocate the fixed transmission cost among the users of firm transmission service. In postage stamp method cost is proportional to MW only. Same price per MW is applied irrespective of distance in the same control area. This method does not require power flow calculations and is independent of the transmission distance and network configuration. The magnitude of the transacted power for a particular transmission transaction is usually measured at the time of system peak load condition. The main purpose of using this methodology is the entire system is considered as a centrally operated integrated system. This method is simpler. Since this method ignores the actual system operation, it is likely to send incorrect economic signal to transmission customers. If transaction crosses a control area, postage stamp of both area should be paid. This effect is called pan-cacking.

Contract Path Method: In this method charging is done on the basis of predefined contract path. Contract path is formed by the shortest route formed by series of transmission lines between contracting nodes. Contract path is not necessarily a physical power flow path hence this method gives doubtful economic signals.

Distance based MW-mile method:

It is load flow based method. It calculates charges associated with each wheeling transaction based on the transmission capacity use. It takes into account following factors:

- Magnitude of transacted power
- Path followed by transacted power
- Distance travelled by transacted power

Charges are calculated as follows:

$$TC_t = TC * \frac{\sum_{k \in K} C_k L_k MW_{t,k}}{\sum_{t \in T} \sum_{k \in K} C_k L_k MW_{t,k}}$$

III POWER TRACING

Power tracing is a tool applied on power flow snapshot that provides complete power audit information like:

1. Share of loads in generation
2. Generators' contribution in loads
3. Decomposition of transmission line flows into generators and load components
4. Loss allocation to generators and loads

The usage allocation calculated by power tracing is always positive and payment is to be unidirectional[11]. The prerequisites for power flow tracing are state estimation solution or power flows over lines, injections at generators and load buses, network topology. There are two versions of power tracing : upstream looking algorithm and downward looking algorithm. In upstream looking algorithm the transmission usage charge is allocated to individual generators and losses are apportioned to loads.

There are two types of tracing approach. Simultaneous Equation Approach requires matrix inversion and easy to code. It converges in presence of circular flows also. Bialek's tracing and Kirschen's method are using this approach. In Graph Theoretic Approach matrix inversion is not required but it fails in the presence of loop flows.

Proportionate Sharing Principle

Proportionate sharing principle is based on Kirchhoff's current low and

it is topological in nature[11]. It is the main principle used for power tracing. It assumes that network node is perfect 'mixture' of incoming flows so that it is impossible to tell which particular electron goes into which particular outgoing line. Figure 1 shows four lines connected to a node, two incoming flows fa, fb and two outgoing flows f1, f2

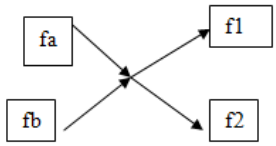

Figure 1: Proportional sharing principle

$$f1 = f1\frac{fa}{fa+fb} + f1\frac{fb}{fa+fb}$$

$$f2 = f2\frac{fa}{fa+fb} + f2\frac{fb}{fa+fb}$$

IV USAGE ALLOCATION BASED PRICING

Real power flow on all network lines are calculated using load flow algorithm. Using Bialek's tracing method transmission line usage by each generator is found out. The magnitude of MW flow found using Bialek's tracing method on every line contributed by different generator is multiplied by its length and predefined weighing factor reflecting the cost per unit capacity of line. Finally, the cost allocated to each generator for a particular line is calculated using the following equations [1].

$$P_{ij}^{g} = \frac{P_{ij}^{g}}{P_i^{g}} \sum_{k=1}^{n} [Au^{-1}]_{ik} P_{Gk} = \sum_{k=1}^{n} D_{ij}{}^{g}{}_{k} P_{Gk}; j \in \alpha_i^{d}$$

where

$$Pi^{g} = \sum_{j \in \alpha_i^{u}} \left| P_{ij}^{g} \right| + P_{Gi}; i = 1, 2, \ldots, n$$

$$[Au]_{ij} = 1; i = j$$

$$[Au]_{ij} = -\frac{|P_{ji}|}{P_j}; j \in \alpha_i{}^{u}$$

$$[Au]_{ij} = o; otherwise$$

The gross power at any node is equal to the generated power at the nodes plus the imported power flows from neighbouring nodes.

Above equation can be implemented using following steps:

1. Solve power flow and define line flows
2. If losses exist, allocate each line's loss as additional loads to both ends of line
3. Find upstream distribution matrix Au
4 Define generation vector P_G
5. Invert matrix Au (i.e. Au^{-1})
6. Find gross power Pg=Au^{-1} P_G
7. Find the gross outflow of line i-j,using proportional sharing princi ple.
8. Total usage of the network by the kth generator (U_{Gk}) is calculated by summing up the individual contributions of that generator to line flows.

III results and discussion

Usage allocation based method take into account magnitude, path followed and distance travelled. Bialek's upstream tracing method is used to find contribution of each generator in transmission line flow. Bus 1 is assumed to be reference bus. Line data is shown in table 1. AC load flow solution is shown in table 2 and 3. Load flow is done using Power world simulator software. Usage allocation using Bialek's tracing

method is done using programming in MATLAB. Transmission usage allocation using Bialek's tracing method is shown in table 4. Figure 4 gives graphical representation of line usage by generator at bus 1 and generator at bus 4. Allocation of transmission charges is shown in table 5.

Line No.	From	To	R	X	B/2	C_kL_k
1	1	2	0.02	0.06	0.030	60
2	1	3	0.08	0.24	0.025	240
3	2	4	0.06	0.18	0.020	280
4	2	5	0.04	0.12	0.015	120
5	3	4	0.01	0.03	0.010	30
6	4	5	0.08	0.24	0.025	240

Table 1: Five bus test system data

Bus	Voltage (pu)	Angle (Deg)	P_L	Q_L	P_G	Q_G
1	1.00000	0.00	----	----	103.84	6.80
2	0.97582	-2.82	50	10	----	----
3	0.98997	-2.76	60	20	----	----
4	1.00000	-2.15	---	----	80	40.59
5	0.94012	-5.63	70	30	-----	----
Total			180	60	183.84	47.39

Table 2: Active and Reactive power at various buses

Line	i	j	P_{ij}^{avg}	P_{ij}^{G1}	P_{ij}^{G4}
1	1	2	84.6	84.6	0
2	1	3	19.2	19.2	0
3	2	4	9.6	0.0	9.6
4	2	5	42.7	38.35	4.35
5	3	4	41.1	0	41.1
6	4	5	29.0	0	29.0

Table 3 :Usage Allocation

Line k	Line cost Rs. (C_kL_k)	$C_kL_kMW_{1,k}$	$C_kL_kMW_{4,k}$
1 (1-2)	3000	253800	0
2(1-3)	12000	230400	0
3(2-4)	14000	0	133400
4(2-5)	6000	230090	26110
5(4-3)	1500	0	61650
6(4-5)	12000	0	348000
Total	48500	714290	569160
$\sum C_kL_kMW_{tk}$		1283450	
T_{ct}		26992.15	21507.85
Cost(Rs/MW)		259.9	268.84

Table 4:Charge allocation

Table 3 indicates that lines 1 and 2 are supplied only through generator at bus 1 hence 100% cost of lines 1 and 2 is allocated to generator at bus 1. Same way lines 3,5 and 6 are are supplied fully through generator at bus 4 hence 100% cost of lines 3,5 and 6 is allocated to generator at bus 4. But for line 4 flow is due to both generators 1 and 4,hence proportional sharing of both generators is found out. Out of 42.7 MW line flow 38.35 MW is because of generator 1 and 4.35 MW is because of generator 4.

Table 5 gives charges allocated to generator 1 and 4.Line cost is already given ($\mathbf{C_kL_k}$) in Rupees. Line cost is multiplied with flow due to each generator($\mathbf{C_kL_kMW_{t,k}}$). Finally cost to be allocated to each generator is calculated considering percentage usage. Generator at bus 1 will pay Rs. 26992 and generator at bus 4 will pay Rs. 21507 as transmission cost.

IV CONCLUSION

In this paper embedded cost based transmission pricing method using power tracing based MW-mile method have been proposed. It overcomes the limitation of postage stamp and contract path methods. As transmission system has become a separate entity ,it has resulted in need to trace the flow of power i.e. to assess the impact of particular generator or load on the power system. Bialek's tracing method is suitable for calculating usage of transmission system.

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