Transmission Cost Allocation Considering Financial Transmission Rights

S.V.N.L. Lalitha, *Member, IEEE*
Koneru Lakshmaiah College of Engineering
Vaddeswaram, Guntur Dt, Andhra Pradesh, India

Maheswarapu Sydulu, *Member, IEEE*
National Institute of Technology, Warangal
Andhra Pradesh, India

Abstract— **This paper presents a flow based transmission network cost allocation method considering the Financial Transmission Rights (FTR). The method makes use of the contributions of generators and demands to line flows and calculates the locational marginal prices (LMP). Based on the LMPs the total FTR credits for the FTR holders for all lines can be calculated.**

Index Terms— **Financial Transmission Rights, Load flow, Locational marginal price, Network usage, Transmission Pricing.**

I. INTRODUCTION

Transmission pricing is one of the most complicated issues in restructuring electricity supply industry because of the physical laws that govern power flow in the transmission network, and the need to balance supply and demand at all times. Since generators and demands are all connected to the same network, actions by one participant can have significant consequences on others making it difficult to investigate the cost, each participant is responsible for [1]. The need to charge all customers on a non discriminatory basis for transmission services made it an open research issue. Derivation of the transmission cost should be simple and transparent.

It is difficult to achieve an efficient transmission pricing scheme that could fit all market structures in different locations. The ongoing research on transmission pricing indicates that there is no generalized agreement on pricing methodology. In practice, each restructuring model has chosen a method that is based on the particular characteristic of its network. Measuring whether or not a certain transmission pricing scheme is technically and economically adequate would require additional standards [2].

Various methods for fair allocation of transmission cost have been reported in the literature. The most common and simplest approach is the so called postage – stamp method, which depends only on the amount of power moved and the duration of its use, irrespective of the supply and delivery points, distance of transmission usage. Contract path method proposed for minimizing transmission charges does not reflect the actual flows through the transmission grid [2]. As an alternative, MW-Mile methodology was introduced in which different users charged in proportion to their utilization of the grid [1] [2]. The key feature in MW-Mile method is to find the contribution or share of each generator and each demand in each of the line flows. One of the significant methods reported for finding the share/contribution of generators and demands is flow based. J.Bialek has proposed a tracing method based on topological approach resulting in positive generation and load distribution factors [4]. D. Kirschen *et al* proposed a method to find the contributions of generators and loads by forming an acyclic state graph of the system making use of the concepts of domains, commons and links [5]. Other methods that use generation shift distribution factors [6] are dependent on the selection of the slack bus and lead to controversial results.

In this paper an attempt is made to calculate the total FTR credits for the FTR holders for all lines in the system. An FTR is a purchased right that can hedge congestion charges on constrained transmission paths. It provides FTR owners with the right to transfer an amount of power over a constrained transmission path for a fixed price. Initially, an acyclic state graph of the system making use of the concepts of domains, commons and links is formed. Making use of the contributions of generators and demands to line flows locational marginal prices (LMP) are found. Based on the LMPs the total FTR credits for the FTR holders for all lines can be calculated.

The organization the paper is as follows. Section II provides the flow based network cost allocation methodology. Section III presents the concepts of LMP and FTR calculations. In Section IV results from a case study on IEEE RTS 24 bus system are presented. Some relevant conclusions are given in Section V.

II. TRANSMISSION COST ALLOCATION

Domain of a Generator

The domain of a generator is defined as the set of busses which are reached by power produced by this generator. Power from a generator reaches a particular bus if it is possible to find a path through the network from the generator to the bus for which the direction of travel is always consistent with the direction of the flow as computed by a power flow program or a state estimator. The concept dual to the domain of a generator could be dubbed to the catchment area of a load and is defined as the set of busses which are reached by power consumed by this load.

Commons

Common is defined as a set of contiguous busses supplied by the same generators. Unconnected sets of busses supplied by the same generators are treated as separate commons. The rank of a common is defined as the number of generators supplying power to the busses comprising this common. It can never be

978-1-4244-2746-8/08/$25.00 © 2008 IEEE

lower than one or higher than the number of generators in the system.

A "load common" is the set of buses which are reached by power flowing towards the same loads. As there are typically more loads than generators in a power system, the load commons tend to be more numerous and smaller than the generator commons.

Links

Having divided the busses into commons, each branch is either internal to a common (i.e. it connects two busses which are part of the same common) or extemal (i.e. it connects two buses which are part of different common). One or more extemal branches connecting the same commons form what will be called a link. It is very important to note that the actual flows in all the branches of a link are all in the same direction. Furthermore, this flow in a link is always from a generator common of rank N to a generator common of rank M where M is always strictly greater than N.

State Graph

Given the direction of the flows in all the branches of the network, unique sets of commons and links are formed. If the commons are represented as nodes and the links as branches, the state of the system can be represented by a directed acyclic state graph. This graph is directed because the direction of the flow in a link is specified.

Contribution to the Load of a Common

The inflow of a common is defined as the sum of the power injected by sources connected to busses located in this common and of the power imported in this common from other commons by links. This inflow is always strictly positive. For root nodes of the state graph it includes only the power injected within the common as there are no imports. The outflow of a common is equal to the sum of the power exported through links from this common to commons of higher rank. The inflow of a common is equal to the sum of its outflow and of all the loads connected to the busses comprising the common.

Further results are dependent on the following proportionality assumption.

For a given common, if the proportion of the inflow which can be traced to generator i is $\mathbf{x_i}$, then the proportion of the outflow which can be traced to generator i is also $\mathbf{x_i}$.

Like all postulates, this assumption can neither be proven nor disproven and its only justification is that it appears more reasonable than any other possible assumption. These other assumptions would imply that the power traceable to some generators is disproportionately consumed in the common while the power traceable to other generators is disproportionately transmitted to other commons .Considering that the definition of a common states that all busses within the common are reached by power traceable to the same set of generators, these competing assumptions do not seem to have any reasonable physical basis. It can easily be shown that the following statement is a corollary or an alternate formulation of the proportionality assumption.

For a given common, if the proportion of the inflow which can be traced to generator **i** is **x,** then the proportion of the load which can be traced to generator i is also **x.**

This assumption provides the basis of a recursive method for determining the contribution of each generator to the load in each common.

$$F_{ijk} = C_{ij} * F_{jk} \tag{1}$$

$$I_k = \sum_j F_{jk} \tag{2}$$

$$C_{jk} = \frac{\sum_j F_{ijk}}{I_k} \tag{3}$$

where the following notations have been used.

C_{ij} : Contribution of generator i to common j

I_k : Inflow of common k

C_{ik} : Contribution of generator i to common k

F_{jk} : Flow on the link between commons j and k

F_{ijk} : Flow between commons j and k due to generator i

For load commons, the proportionality assumptions can be expressed as follows:

For a given load common, the proportion of the outflow which can be traced to load i is x_i, then the proportion of the generation in this common and the flow into this common which can be traced to load i is also x_i.

Bundling the buses into load commons and the branches into the corresponding links, a given pattern of injections and flows leads to another acyclic graph. Load contributions are computed by starting from the leave nodes (i.e. the load commons which contain only one load) and going through this graph apportioning outflows instead of inflows.

Once the contributions of generators and loads are calculated, cost allocation can be done using the MW-mile methodology [6].

SECTION III

Locational marginal prices:

LMP is the marginal cost of supplying the next increment of electrical energy at a specific bus considering the generation marginal cost and the physical aspects of the transmission system.

LMP = Generation marginal cost + congestion cost + cost of marginal losses

LMP is the additional cost for providing one additional MW at a certain node. Using LMP, buyers and sellers experience the actual price of delivering energy to locations on the transmission systems.

First step is to determine all marginal generators that supply the incremental power demand on each bus. For the buses connecting marginal generators in a power system, the LMP value of a particular bus is equal to the marginal price of the particular generator connected to that bus. For other buses without marginal generators, the LMP value of a particular bus depends on the contribution of marginal generators to line power flows corresponding to that bus. [2]

Finding the LMPs based on the contributions of each marginal generator j to each line flow ($f_{m-n,i}^{g_j}$) is given below. LMP value of a particular bus connected to a marginal generator is taken as equal to the marginal price of the particular generator connected to that bus. For other buses, LMP is calculated using the following equation.

$$LMP_i = \sum_{all\ generators} LMP_j \frac{\sum | f_{m-n,i}^{g_j} |}{\sum_{m-n \in \Omega_l} | f_{m-n,i} |} \quad (4)$$

where Ω_l is the set of all adjacent lines connected to that bus and $f_{m-n,i}$ represents the active power flow in line m-n.

Firm Transmission Rights

A firm transmission right is a purchased right that can hedge congestion charges on constrained transmission paths. In other words, it provides FTR owners with the right to transfer an amount of power over a constrained transmission path for a fixed price.

Market participants pay congestion charges under a constrained situation based on LMP differences. These charges arise when the energy demand across a transmission path is more than the capability of transmission lines on that path. Under constrained situations, each participant is charged for congestion based on the MWh value of generation ordered to serve its load. The charge will be passed on MWh and the difference in LMPs of injection and extraction points. If it happens that a market participant's generation is not exactly equal to its load, it will either purchase or sell energy to the spot market [2].

Each FTR holder receives a congestion credit in each constrained hour that is proportional to the FTR value. This credit allocation is based on preferred schedules, while congestion charges are based on actual deliveries. From the preferred schedule FTRs, the total congestion credits are calculated and compared with the total congestion charges, which are based on the cost of re-dispatched schedules at each hour. If the total congestion credits are less than or equal to the total congestion charges, the congestion credit for each FTR holder is equal to the one calculated. If there are any extra congestion charges, the extra charges are distributed among market participants at the end of the month. Otherwise, the congestion credit for each FTR will be equal to a share of total congestion charges may be offset by excessive charges in other hours at the end of the accounting month [2].

There are four ways to acquire FTRs:

1. Network integration service customers acquire FTRs upto the value of their peak loads from capacity resources to their aggregate loads.
2. Firm point – to- point service customers acquire FTRs from source to destination.
3. FTRs may be traded monthly through an auction conducted by the ISO or an auctioneer replacing the ISO.
4. FTR holders may trade with other market participants in secondary markets (bilateral transactions) without participating in the FTRs auction.

To purchase a certain FTR in the auction, bidders provide the following information: maximum amount of FTR the bidder is willing to pay for, bid price, and points of injection and extraction. To sell a certain FTR in the auction, bidders provide the following information: maximum amount of FTR the bidder is willing to be paid for, bid price, and points of injection and extraction.

Calculation of FTR credit:

As shown in Fig.1, when a participant X holds an FTR between points m-n ($FTR_{mn,x}$), the participant is entitled to a credit ($Cr_{mn,x}$) as

$$Cr_{mn,x} = FTR_{m-n,x} \times (LMP_n - LMP_m) \quad (5)$$

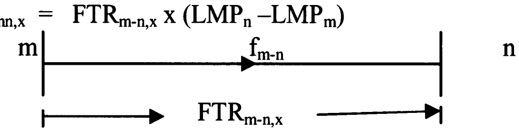

Fig. 1. 1 Total Flow and FTR between m and n

If there are more than one FTR holder on line m-n, then the total FTR credits for line m-n is

$$Cr_{mn} = \sum_x FTR_{m-n,x} \times (LMP_n - LMP_m) \quad (6)$$

The holder X's credit comes from congestion charges for this line. If FTR_{m-n} is less than f_{m-n}, that is the FTR on m-n is less than the total flow on line m-n, the collected charges for this line are adequate to cover FTR credits on this line, and each holder gets $Cr_{m-n,x}$, calculated from (5). In this case extra credit will be paid to the transmission line owner. Otherwise, FTR_{m-n} will be larger than f_{m-n} and the owner of line m-n should pay the difference. The ISO will manage these transactions in either case.

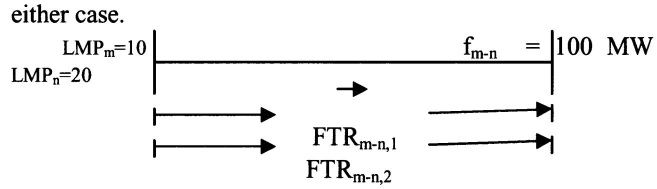

Fig. 2 Total Flow and FTR between m and n

For instance, in fig. 2, if the congestion cost is \$1000, $FTR_{m-n,1}$ = 40MW, $FTR_{m-n,2}$ = 50 MW, then total FTR credits for the line as calculated from (6) is \$900. In this case, the ISO will get \$1000 from congestion charges, pay \$900 to FTR holders (\$400 to holder 1, \$500 to holder 2), and the extra \$100 will be paid to the owner of line m-n.

IV. CASE STUDY

The results obtained from the case study performed on the IEEE 24-bus Reliability Test System [11] given in Fig. 3 are presented.

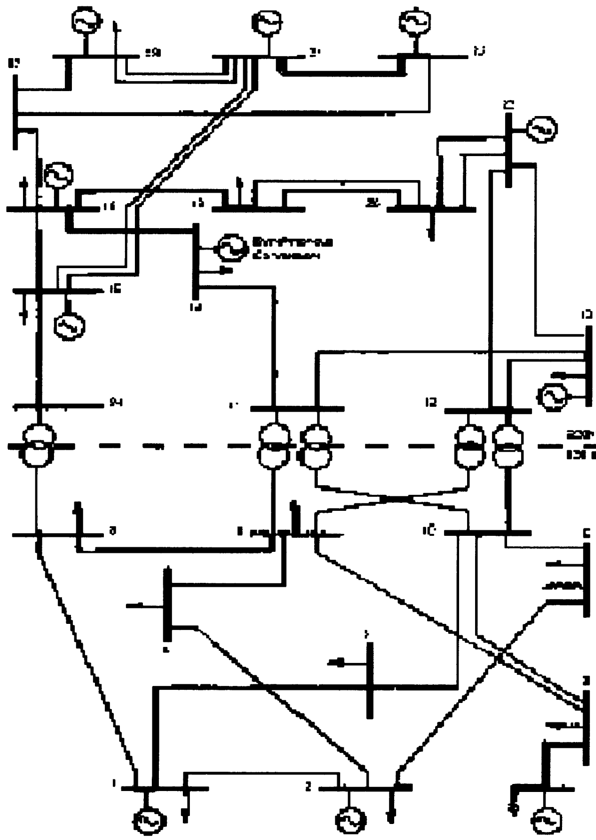

Fig.3. IEEE RTS 24 bus system

The data pertaining to converged power flow is of IEEE RTS peak load, taking place on the Tuesday of week 51 from 5 P.M. to 6 P.M. [11]. The costs of the lines are considered to be proportional to their respective series reactance [2].

TABLE I
Marginal Prices of Generators

Generator Number	Marginal Price in $/MWH
1	28.04
2	28.04
7	30.08
13	27.44
15	23.1
16	23.1
18	19
21	19
22	19.01
23	16.6

For calculation of LMP, the following marginal costs shown in Table I are taken for generators and all generators are assumed to be marginal generators. Calculation of LMPs at all load buses is done using the expression given in (4).

TABLE II
Locational Marginal Prices at all buses

Bus No	LMP in $/MWH	Bus No	LMP in $/MWH
1	28.04	13	27.44
2	28.04	14	20.337
3	20.3717	15	23.1
4	24.6716	16	23.1
5	26.4879	17	19.0042
6	23.3919	18	19
7	30.08	19	19.4622
8	27.0263	20	16.6
9	21.0437	21	19
10	21.0794	22	19.01
11	20.8443	23	16.6
12	19.6333	24	20.3717

Once the LMPs are obtained, the FTR credits can be calculated easily using the expression given in (5) or (6).

V. CONCLUSIONS

A flow based method to determine the transmission cost allocation considering the Financial transmission Rights is presented. In the restructured scenario, this method gives a simple method for the determination of LMPs. The method can be used as a powerful tool in the transmission cost allocation problem. The method provides an insight into not only the transmission cost allocation problem but also the calculation of FTR credits.

REFERENCES

[1] "*Power System Restructuring and Deregulation – Trading, Performance and Information Technology*" Edited by Loi Lei Lai, John Wiley & Sons Ltd,Chichester.

[2]Mohammed Shahidehpour, Hatim Yamin, Zuyi Li, "*Market Operations in Electric Power System – Forecasting,Scheduling and Risk managements*", John Wiley & Sons Ltd, Newyork

[3] Jiuping Pan, Yonael Teklu, Saifur Rahman,, *"Review of Usage-Based Transmission Cost Allocation Methods under Open Access "*, IEEE Transactions On Power Systems, Vol. 15, No. 4, November 2000

[4] J. Bialek, "Topological generation and load distribution factors for supplement charge allocation in transmission open access," *IEEE Trans Power Syst.*, vol. 12, no. 3, pp. 1185–1193, Aug. 1997.

[5] D. S. Kirschen, R. N. Allan, and G. Strbac, Contributions of individual generators to loads and flows," *IEEE Trans. Power Syst.*, vol. 12, no. 1, pp. 52–60, Feb. 1997.

[6] Meng, Yi; Jeyasurya, Benjamin, "Investigation of Transmission Cost Allocation Using a Power Flow Tracing Method" , *Power Engineering Society General Meeting, 2007 IEEE* Volume , Issue , 24-28 June 2007 Page(s):1 – 7

[7] Paul R. Gribik, Dariush Shirmohammadi, Joseph S. Graves and James G. Kritikson, "Transmission Rights and Transmission Expansions", *IEEE Transactions On Power Systems*, vol. 20, no. 4, November 2005 ,pp.1728-1737

[8] K.Bhattacharya, M.H.J.Bollen and J.E.Daalder, "*Operation of restructured Power Systems",* Kluwer Academic Publishers,Boston,2001

[9] Antonio J. Conejo, Enrique Castillo, Roberto Mínguez, and Federico Milano, "Locational Marginal Price Sensitivities", *IEEE Transactions On Power Systems*, VOL. 20, NO. 4, pp.2026-2032,NOVEMBER 2005

[10] Juan Carlos Mateus, Pablo Cuervo Franco, "Transmission Loss Allocation Through Equivalent Bilateral Exchanges and Economical Analysis", *IEEE Transactions On Power Systems*, Vol. 20, No. 4, November 2005, pp.1799-1805

[11] Reliability Test System Task Force, "The IEEE reliability test system 1996," *IEEE Trans. Power Syst.*, vol. 14, no. 3, pp. 1010–1020, Aug. 1999.