Transmission Tariffs in Competitive Electricity Markets

Judite Ferreira, Zita vale, Hugo Morais

GECAD – Knowledge Engineering and Decision-Support Research Group of the Institute of Engineering – Polytechnic of Porto (ISEP/IPP), Rua Dr. António Bernardino de Almeida, 4200-072 Porto, Portugal

(e-mail: *mju@isep.ipp.pt*, *zav@isep.ipp.pt, hgvm@isep.ipp.pt*)

Abstract In context of electricity market, the transmission price is an important tool to an efficient development of the electricity system. The electricity market is influenced by several factors; however the transmission network management is one of the most important aspects, because the network is a natural monopoly. The transmission tariffs can help to regulate the market, for that reason evaluate tariff must have strict criterions.

This paper explains several methodologies to tariff the use of transmission network by transmission network users. The methods presented are: Post-Stamp Method; MW-Mile Method; Distribution Factors Methods; Tracing Methodology; Bialek's Tracing Method and Locational Marginal Price.

Introduction

In traditional power sector based on vertically integrated utilities (generation transmission plus distribution, and retail) is moving toward a new structure of vertical disintegration. In the wholesale power market, all generators compete to sell to all distributors or directly to customers and retailers if retail competition is allowed. Under this new unbundled structure of generation and transmission with competitive trading between wholesale market participants, the traditional pool operating functions have been more clearly defined and segregated into: Market operation functions and System operation functions. The market operation functions associated to energy trading, scheduling, and settlement of energy transactions in different time horizons and the system operation functions related to operation and control of the bulk power system to meet load and security needs with a real time dispatch to balance supply and demand to manage ancillary services and to maintain system reliability, and to manage transmission congestion [1].

The effective competition in reformed wholesale electricity markets can only be achieved if the following six prerequisites are met: separation of the grid from generation and supply; wholesale price deregulation; sufficient transmission capacity for a competitive market and non-discriminating grid access; excess generation capacity developed by a large number of competing generators; an equilibrium relationship between short-term spot markets and the long-term financial instruments that marketers use to manage spot - market price volatility; an essentially hands-off government policy that encompasses reduced oversight and privatization. The absence of any one of the first five conditions may result in an oligopoly or monopoly market whose economic performance does not meet the efficiency standards of a competently managed regulated electrical utility [2].

An important issue to guarantee effective wholesale electricity competition concerns the division of responsibilities into owning, operating, and regulating the transmission system. A cornerstone of restructuring is the separation of generation from transmission. Under this segregated structure, transmission companies and systems operators continue to be regulated. All Transmission Systems Owners (TRANSCOs) must provide comparable and nondiscriminatory service to independent generators. The availability of transmission installations and the location of new transmission investments significantly affect trading opportunities.

In spite of the deregulated electricity market to have separated the activities of the transmission and production, the electrical transmission networks are assumed as a natural monopoly. This is due to the economic (and sometimes even physical) impossibility of the existence of several alternative infrastructures as transmission networks. Anyway, this monopoly cannot constitute an obstacle for the activities of the agents who act in these markets. So the existence of adequate regulation that guarantees the access to the transmission electrical network is required [3]. Many authors argue that the transmission network is a key element in the process of liberalizing the electricity market. Within this concept, the transmission tariff system and the user costs allocation must preserve an adequate resource allocation among market agents [4].

Evaluate of transmission tariff can reflect the real impact in the transmission network users and in the distribution costs. There are several methods for transmission costs allocate.

2 Methodologies for Transmission Cost Allocation

In general, all methodologies for transmission charges present advantages and disadvantages, each methodology using different ways to allocate the costs due to the use of the transmission network. The Post-Stamp and the contract path are two primarily methods for transmission allocation [4].These methods are simple and can be easily implemented, but they do not consider the actual transmission network use and do not provide adequate economic signals aiming at efficient transmission network use. Some methods, as the MW-mile method [5], consider the power flow impact that each agent causes in each line of the transmission network. Marginal methods are other methodology for allocation operational as well as embedded costs of transmission networks.

Different methodologies for transmission cost allocation have appeared in recent years. The *pro-rata* method present allocates costs to generators and demands according to the sum of active power produced/consumed by each generator/demand.

Other methods more complex, distribute the cost based on the active power flow produced by generators and demands through the transmission lines. These methods use the proportional sharing principle, where the flow attributed to each generator and demand in upstream lines, determine the power flows through downstream lines. Thus, these flows are associated with the origins and destinations, i.e., generators and demands. More details of this method can be found in [6] and [7].

The nodal method used in many countries, allocates the network usage costs and provides a measure to this allocation based on optimal power flow sensitivity in each line due to the power injected at each bus.

The network usage method uses equivalent bilateral exchanges to allocate costs to generators and demands. Thus, each demand is attributed a generation fraction and, a fraction of each demand is attributed to each generator. The cost attribution by the network usage method occurs considering the impact in terms of power flow of each equivalent bilateral exchange in each transmission line obtained by DC power flow solution.

The Z_{bus} method [8] presents a solution based on the Z_{bus} matrix and considers the current injection at each bus. The combination of Z_{bus} matrix and currents injections, determines the measure of sensitivity that indicates what the individual contribution of each current injection to produce the power flow through of a transmission line.

2.1 Post-Stamp Method

Postage Stamp method is traditionally used by electric utilities to allocate the fixed transmission cost among the users firm transmission service [4]. This method is an embedded cost method, which also called rolled-in embedded method. This method does not require power flow calculations and is independent of the transmission distance and network configuration. In the other words, the charges associated with the use of transmission system determined by postage stamp method are independent of the transmission distance, supply and delivery points or the loading on the different transmission facilities caused by the transaction under study. The method is based on the assumption that the entire transmission system used, regardless of the actual facilities that carry the transmission service. The method allocates charges to a transmission user based on an average embedded cost and magnitude of the user's transacted power.

The expression (1) e (2) allow evaluate the tariff *R(u)* imputed to each transaction *u*.

$$P = \frac{CT}{\sum_{g} PG(g)} \quad (1)$$

$$R(u) = P \times W(u) \quad (2)$$

Where

CT is the total cost to share ($/MW)
W(u) Active Power transitioned (MW)

Post-Stamp method has several disadvantages because does not give economical signals. This method to tariff the transmission only reflects the energy transitioned independently the use or not the transmission network.

2.2 MW-Mile Method

MW-Mile method, existing network costs of transmission system are allocated proportionally to the MW power flows caused by a customer in a transmission network [5]. This method is an embedded cost method that is also known as a line by line method, because it considers, in its calculations, changes in MW transmission flows and transmission line lengths. The tariff P is evaluated by:

$$P = \frac{CT}{\sum_{k} F_k \times L_k} \quad (3)$$

Where

CT is the total cost to share ($/MW*mile)
F_k is the power flow in line *k* (MW)
L_k is the line length (mile)

The method MW-Mile evaluate charges associated with each wheeling transaction based on transmission capacity use as a function of the transact power, the path followed by transacted power. This method depends on operational system configuration usually used the dc power flows but also can used in ac.

2.3 Distribution Factors Methods

Distributions factors are sensitivity factors that allow evaluating the line flows. These factors are calculated based on linear load flows, they are used in the proposed methodology to approximately determine the impact of each generator and load on transmission line flows [9].

2.3.1 Generalized Generation Distribution Factors

The Generalized Generation Distribution Factors (GGDFs or D factor) determine the impact of each generator in line flows. The expression used to calculate the GGDF is:

$$D_{ik,p} = D_{ik,r} + A_{ik,p} \tag{4}$$

The $A_{ik,p}$ factor is evaluated using the reactance matrix and dc power flow approximation. This factor represents the incremental use of the transmission network and depends only on the transmission network characteristics.

The GGDF factor of the reference bus can be obtained as follows:

$$D_{i\,k,r} = \frac{P_{i\,k}^{0} - \sum_{\substack{p=1 \\ p\neq r}}^{N} A_{i\,k,p} \cdot G_p}{\sum_{p=1}^{N} G_p} \tag{5}$$

The impact in line flows evaluated by this method is not an incremental value but is absolute.

GGDF factor depends of the characteristics lines, but it does depend of the reference bus. GGDF factor depends on the operation point.

2.3.2 Generalized Load Distribution Factors

The Generalized Generation Distribution Factors (GLDFs or C factor) determines the impact use of each load in line flows. The expression used in the simulator proposed in this paper is:

$$C_{i\,k,m} = C_{i\,k,r} + A_{i\,k,m} \tag{6}$$

The GLDF factor of the reference bus can be obtained as follows:

$$C_{i\,k,r} = \frac{P_{i\,k}^{0} - \sum_{\substack{m=1 \\ m \neq r}}^{N} A_{i\,k,m} \cdot L_m}{\sum_{m=1}^{N} L_m} \tag{7}$$

The impact in line flow evaluated by this method is not an incremental value but it is an absolute one.

GLDF factor depends of the characteristics lines, but it does depend of the reference bus and the GLDF factor depends on the operation point.

2.4 Tracing Methodology and Bialek's Tracing Method

The section 2.4 explains the principles concepts of the tracing methodology and the proportional sharing. The second part of this section show how to apply this math technique in the Bialek's tracing algorithm.

2.4.1 Tracing Methodology

The core of the power flow tracing method [9] is the power flow proportional sharing principle, which says that for every node in a network, the proportion of power flow on each outflow branch fed by each inflow branch is equal to the proportion of the inflow from this branch in the total inflows.

For example, in fig. 1, there are 4 branches connected with node i, where q_j and q_k are the inflow branches and q_m and q_l are the outflow branches.

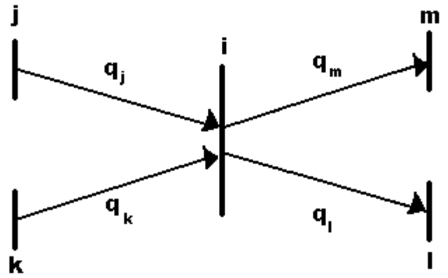

Fig.2 .1 Proportional *Sharing*

Taking into account the *Kirchhoff* laws, we have*:*

$$q_j + q_k = q_m + q_l \tag{8}$$

Nodes j e k can represent producers connected directly on bus i, and node m and node l can represent consumers connected on node i.

The outflow q_m is compose by two components in function of q_k and q_j.

$$q_m = \frac{q_j}{q_j + q_k} * q_m + \frac{q_k}{q_j + q_k} * q_m \tag{9}$$

The same way, q_l, q_j, q_k.

$$q_l = \frac{q_j}{q_j + q_k} * q_l + \frac{q_k}{q_j + q_k} * q_l \tag{10}$$

$$q_j = \frac{q_m}{q_m + q_l} * q_j + \frac{q_l}{q_m + q_l} * q_j \tag{11}$$

$$q_k = \frac{q_m}{q_m + q_l} * q_k + \frac{q_l}{q_m + q_l} * q_k \tag{12}$$

This way to evaluate the shares can be applied to all nodes of the transmission network. The goal is to calculate the power flow impact provoked by the transactions.

2.4.2 Bialek's Tracing Methodology

Tracing methods are based on ac power flow methods aiming to determine the contribution of transmission users to transmission usage. Tracing methods could be used for transmission pricing and recovering fixed transmission costs. In this work, we discuss one tracing method, which are recognized as the Bialek's tracing method. Thus, in this method, it is assumed that nodal inflows are shared proportionally among nodal outflows [9, 10].

This method is used to evaluate the contribution of the generators in the losses in each transmission network branch.

To show how is algorithm works; it is define the gross demand as the sum of a particular generator and its allocated part of the total transmission loss. The total gross in a system is equal to total actual generation. Topological distribution factors are given by following equation in which $D^{g}_{ik,p}$ refers to the k^{th} generator's contribution to line *i*-*k* flow.

$$p^{g}_{ik} = \frac{p^{g}_{ij}}{p^{g}_{i}} \sum_{p=1}^{n} \left[A_u^{-1} \right]_{ip} P_{G_p} = \sum_{p=1}^{n} D^{g}_{ij,p} P_{Gp}; \;\; j \in \alpha^{d}_{i} \tag{13}$$

Where

$$p^{g}_{ik} = \sum_{k \in \alpha^{u}_{i}} \left| P^{g}_{ik} \right| + P_{G_i}; \qquad i = 1, 2, ..., n \tag{14}$$

$$\lfloor A_u \rfloor_{ik} = \begin{cases} 1 & i = k \\ -\dfrac{\left| P^{g}_{ik} \right|}{P_k} & k \in \alpha^{u}_{i} \\ 0 & otherwise \end{cases} \tag{15}$$

The gross power value at any bus is equal to the generated power amount at the bus taking into account the imported power flows from neighboring bus. The total usage of the network by the k^{th} generator (U_{GP}) is calculated by summing up the individual contributions (multiplied by lines weights) of this generator to line flows. His value could be given by:

$$U_{Gp} = \sum_{i=1}^{n} \sum_{k \in \alpha_i^d} W_{ik}^{p} D_{ik,p}^{p} P_{G_p} = P_{G_p} \sum_{i=1}^{n} \left\{ \frac{\left[A_u^{-1} \right]_{ip}}{p_i^p} \sum_{j \in \alpha_i^d} C_{ik} \right\} \quad (16)$$

2.5 Locational Marginal Price

In competitive electricity markets, LMP are important pricing signals for the participants as the effects of transmission losses and biding constraints are embedded in LMP. While these LMP provide valuable information at each location, they not provide a detailed description in terms of contribution terms. The LMP components, on the other hand, show the explicit decomposition of LMP into contribution components, and thus, can be considered as better market signals [11].

After solving congestion, the standard locational price for location *i* and time *t* is calculated as:

$$LMP_i aux = LMP^{energy} + LMP_i^{cong} \quad (17)$$

Where:

LMP^{energy} marginal energy price of system ($/MWh)

LMP_i^{loss} marginal loss price at bus *i* ($/MWh).

The shadow price is the change in the objective value of the optimal solution of an optimization problem obtained by relaxing the constraint by one unit. In a business application, a shadow price is the maximum price that management is willing to pay for an extra unit of a given limited resource.

Locational marginal pricing is a market-pricing approach used to manage the efficient use of the transmission system when congestion occurs on the bulk power grid.

LMP consist of three components as follows:

$$LMP_i = LMP^{energy} + LMP_i^{loss} + LMP_i^{cong} \quad (18)$$

where

LMP_i	locational marginal price at bus *i* ($/MWh)
LMP^{energy}	marginal energy price of system ($/MWh)
LMP_i^{loss}	marginal loss price at bus *i* ($/MWh)
LMP_i^{cong}	marginal congestion price at bus *i* ($/MWh).

The loss and congestion components are defined as follows:

$$LMP_i^{loss} = (DF_i - 1) * LMP^{energy} \tag{19}$$

$$LMP_i^{cong} = -\sum_{l \in K} GSDF_l * \beta_l \tag{20}$$

Where:

DF_i	delivery factor at bus *i*
$GSDF_l$	generation Shift Factor at line *l*
B_l	constraint incremental cost (shadow price) associated with line k
k	*set of congested transmission lines.*

2.5.1 Penalty Factors and Delivery Factors

The Penalty Factor associated with any bus on the transmission system is defined as the increase required in injection at that bus to supply an increase in withdrawn at the system reference bus with all other bus net injections held constant. Mathematically, the Penalty Factor for bus *i* can be calculated as:

$$PF_i = \frac{1}{\left(1 - \frac{\partial P_{Loss}}{\partial P_i}\right)} \tag{21}$$

Where

$-\dfrac{\partial P_{Loss}}{\partial P_i}$ - is the incremental transmission loss and can be calculated *by*

$$\frac{\partial P_{Loss}}{\partial P_i} = \frac{\partial}{\partial P_i}\left(\sum_{l=1}^{nl} P_l^2 \times R_l\right) \tag{22}$$

Equation (22) can be reformulated as equation (23) and equation (24).

$$\frac{\partial P_{Loss}}{\partial P_i} = \frac{\partial}{\partial P_i}\left(\sum_{l=1}^{nl}\left(\sum_{i=1}^{ni} A_{i,l} \times P_i\right)^2 \times R_l\right) \tag{23}$$

$$\frac{\partial P_{Loss}}{\partial P_i} = \left(2 \times \sum_{l=1}^{nl} A_{i,l} \times \left(\sum_{i=1}^{ni} A_{i,l} \times P_i\right) \times R_l\right) \tag{24}$$

where

P_i - net injection at bus i (MW)

P_l - power flow in line l (MW)

R_l - line resistance (ohm).

In the marginal loss pricing formulation, the Delivery Factors are also needed in addition to the Penalty factors.

The Delivery factor of bus i can be calculated as in (25):

$$DF_i = \left(\frac{1}{PF_i}\right) = \left(1 - \frac{\partial P_{Loss}}{\partial P_i}\right) \tag{25}$$

3 Conclusions

In the context of competitive electricity markets, electrical transmission networks are assumed as a natural monopoly. Anyway, this monopoly cannot constitute an obstacle for the activities of the agents who act in these markets. The transmission tariff allows charging the cost associated at the transmission network. Present paper explains some methodology to charge the fixed transmission costs. This methodology has different ways to allocate the cost by users of the transmission network. The methods presented are: Post-Stamp Method; MW-mile; Distribution Factors; Tracing Methodology; Bialek's Tracing Method and Locational Marginal Price.

References

1. Geoffrey Rothwell, Tomás Gómez, Electricity Economics _Regulation and Deregulation, Book, Copyright 2003 by Institute of Electrical and Electronics Engineers.
2. Dicorato, A. L'Abbate, A. Minoia, M. Trovato, Electric Power Systems Research, Volume 66, Issue 2, August 2003, Pages 179-186 M.
3. Tan, C.S.; Yun Liu; Lo, K.L., A more transparent way of financial settlement for congestion cost in electricity markets, Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, 2008. DRPT 2008, pp.291-296, 6-9 April 2008.
4. Abhyankar, A. R.; Soman, S. A.; and Khapard, S. A., Optimization Approach to Real Power Tracing: An Application to Transmission Fixed Cost Allocation, IEEE transactions on power systems, vol. 21, no. 3, August 2006.
5. Madiji Q., M.; Ghazizadeh, M. S.; Afsharnia, S., A novel approach to allocate transmission embedded cost based on MW-Mile method under deregulated environment, IEEE Electrical Power & Energy Conference.
6. J. Bialek, Topological generation and load distribution factors for supplement charge allocation in transmission open access, IEEE Trans. Power Syst. 12 (1) (1997) 52–60.
7. D.S. Kirschen, R.N. Allan, G. Strbac, Contribution of individual generators to loads and flows, IEEE Trans. Power Syst. 12 (1) (1997) 52–60.
8. A.J. Conejo, J. Contreras, D.A. Lima, A. Padilha-Feltrin, Zbus transmission network cost allocation, IEEE Trans. Power Syst. 22 (1) (2007) 342–349.
9. Alexander Galetovic, Rodrigo Palma-Behnke, Can generalized distribution factors lead to 'objective' transmission toll allocations? Some lessons

from the recent Chilean experience, Energy Economics, Volume 30, Issue 2, March 2008, Pages 249-270.

10. Jing, Zhaoxia and Wen, Fushuan, Discussion on the Proving of Proportional Sharing Principle in Electricity Tracing Method, 2005 IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China, 2005.
11. Yog Raj Sood, N.P. Padhy, H.O. Gupta, Deregulated model and locational marginal pricing, Electric Power Systems Research, Volume 77, Issues 5-6, April 2007, Pages 574-582.
12. Judite Ferreira, Zita Vale, Ricardo Puga, “Nodal Price Simulation in Competitive Electricity Markets”, Proceedings of 6th International Conference on the European Electricity Market, EEM 09, May 2009, Leuven, Belgium.