Financial Transmission Rights Auctions: Entry and Efficiency

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Abstract

Financial transmission rights (FTRs) are currently a topic of debate in New Zealand. Their purpose is to alleviate the risk associated to locational marginal pricing of electricity. In this paper we review the FTR auction design in practice and discuss the efficiency results for such auctions.

Key words: Financial Transmission Rights, Auctions, Electricity Markets.

1 Introduction

In the New Zealand wholesale electricity market, as well as many other jurisdictions world-wide, electricity supply is scheduled using an optimization model that minimizes the total cost of generation of electricity while complying with physical network constraints. (In New Zealand, this optimization problem is the Scheduling, Pricing and Dispatch (SPD) model that is solved by the transmission owner and operator, Transpower.) The solution provides optimal dispatch of electricity and the economically efficient spot prices for each node of the transmission network (these prices are referred to as locational marginal prices).

Although the wholesale market clearing problem, mentioned above, is an effective mechanism in integrating the power flow constraints, as a by product, it poses financial risk for generators and consumers, who have to pay the locational price of electricity. Figure 1 below (reproduced from the Locational Price Risk Management Analysis presentation (Sept 2010,) available from the the Electricity Commission's website,) depicts the average monthly price differences between the Otahuhu and Benmore nodes since January 2008. It is easy to observe from this figure that locational price differences can be substantial. A financial transmission right (FTR), otherwise known as a transmission congestion contract (TCC), is a financial instrument designed to manage risk associated with locational marginal price volatility. FTRs were first introduced by Hogan (Hogan 1992) and are used in several jurisdictions in the US including the Pennsylvania-New Jersey-Maryland (PJM) and

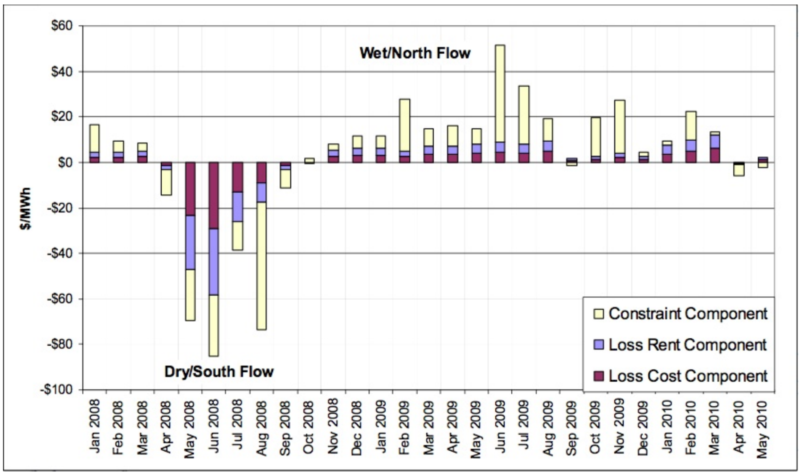

Figure 1: Average monthly price differences across Benmore and Otahuhu.

New York markets. Suppose that for a given period that the price at Otahuhu is \$40.00 more than that at Benmore. Then a firm equipped with an FTR of 100 MW from Benmore to Otahuhu, for that period, would be paid a coupon payment of $100 \times \$40.00 = \$4000.00$.

In the simplest form of FTR, the holder specifies a volume in MW and two nodes, an upstream and a downstream node, in a transmission network. The price at the downstream node minus that at the upstream node is multiplied by the FTR volume (specified in MW) and is paid to the holder as a coupon payment, for each period when the FTR is valid. These FTRs are referred to as *balanced point-to-point FTRs*. If the payment for an FTR can be exercised as an option, that is, it is only exercised if the downstream price exceeds the upstream price, then we have a so called *option FTR*. In absence of this requirement, the holder must pay the system operator any price difference between the downstream and upstream nodes multiplied by the FTR volume and this is termed an *obligation FTR*. An FTR can be specified more generally by a vector of nodal loads and injections, specified in MW, where the loads are taken to be positive. The coupon payment for any period is the inner product of this vector with the vector of nodal prices. In this paper we review revenue adequacy and simultaneous feasibility of extant FTRs. We will then outline the form of the current FTR auctions and provide some simple examples. We will discuss the efficiency of these auctions.

2 Revenue Adequacy, Simultaneous Feasibility and the FTR auction problem

In this section we will discuss the problem of revenue adequacy in a transmissions rights auction and provide results that ensure revenue adequacy under a set conditions referred to as the simultaneous feasibility conditions. Subsequent to this we will present the FTR auction clearing problem that is currently in use in various jurisdictions such as PJM and NYISO. We end this section by examining some simple examples to illustrate certain properties of these auctions. The examples attempt to capture the key features, as such we have tried to keep them as simple as possible.

Once an auction is settled and FTRs are allocated, the system operator is bound by an agreement to pay the FTR holder the corresponding coupon payment on the FTR for every period for which the FTR is valid. In each period, the ISO collects any congestion rent and redistributes these rents through FTRs. Therefore to maintain its credit standing, the ISO must ensure that the revenue collected with locational prices in the dispatch should at least be equal to the payments to the holders of FTRs in the same period. This property is referred to by the term *revenue adequacy.*

Revenue adequacy is guaranteed through the *simultaneous feasibility test* for the general case of economic dispatch problems when the transmission constraints are convex. To make this precise, we will follow the notation from Philpott and Pritchard (Philpott and Pritchard 2004). Consider the economic dispatch problem given by

$$\begin{array}{lll} \text{EDP: minimize} & \sum_i \sum_{j\in O(i)} c_j x_j & \\ \text{subject to} & g_i(f) + \sum_{j\in O(i)} x_j = d_i, & i = 1, 2, \cdots, n \\ & x \in X & \\ & f \in U. & \end{array}$$

Here

- x_j is the level of dispatch of tranche $j \in O(i)$ where $O(i)$ indicates the set of offered tranches at node i of the transmission network.
- c_j is the offer price (therefore the cost to the system) of tranche $j \in O(i)$.
- d_i is the demand at node i.
- f denotes the vector of flows on the transmission network links.
- $g_i(f)$ is a concave function that gives the amount of power flow entering node i when link flows are f. The function g takes account of any power losses in the network and we are assuming in this model that this function is concave. Clearly concave piecewise quadratic or linear loss functions would qualify here.
- We assume that X is a convex set that defines the tranche levels.
- We assume that the set of flows f lies in a convex set U that encapsulates any line capacities and other electrical constraints such as the loop flow constraints.
- The first constraint in the economic dispatch problem simply states that demand must be met at every node by production at the node and any electricity flowing into that node.

Using the constraints from EDP we can define the simultaneous feasibility test for obligation FTRs succinctly. Let the vector $h(\alpha)$ denote an extant obligation FTR contract for $\alpha = 1, 2, \cdots, A$ (this set is the index set for the FTRs, each or a number of which may belong to a player in the FTR market). For example a balanced point-to-point FTR of magnitude τ with upstream node i and downstream node j will be represented by the vector h where

$$h_k = \begin{cases} \tau & \text{if } k = j \\ -\tau & \text{if } k = i \\ 0, & \text{otherwise.} \end{cases}$$

The set of FTRs $h(\alpha)$ for $\alpha = 1, 2, \cdots, A$ are simultaneously feasible if and only if there exists a vector y where

$$\text{SFT:} \quad \begin{array}{l} g_i(y) = \sum_\alpha h_i(\alpha), \quad i = 1, 2, \cdots, n \\ y \in U. \end{array}$$

That is, treated as injections and withdrawals, the set of all FTRs that are extant for a single period, must comply with the transmission network constraints simultaneously.

A series of results prove that conditions specified in SFT are sufficient to guarantee revenue adequacy. The first of these results is by Hogan (Hogan 1992) for lossless networks, extended to quadratic losses by Bushnell and Stoft (Bushnell and Stoft 1996). Hogan subsequently proved a more general result extending the previous results to the case of nonlinear but smooth constraints. Philpott and Pritchard (Philpott and Pritchard 2004) prove that if EDP can be replaced by a convex problem, that is if the convexified version of the EDP delivers the same optimal solution as the EDP, then SFT is sufficient for revenue adequacy. In general EDP is not equivalent to a convex problem. For instance for periods when some nodal prices are negative (in presence of losses), EDP can not be reformulated as a convex problem that will deliver the same solution. Philpott and Pritchard (Philpott and Pritchard 2004) have demonstrated that in such periods the ISO may be faced with revenue inadequacy.

2.1 The FTR Simultaneous Feasibility Auction

As mentioned above, the ISO must ensure revenue adequacy for meeting its obligation of paying out the extant FTR coupon payments. Revenue adequacy must be ensured under every possible ensuing network configuration. Therefore the simultaneous feasibility test introduced above is replicated for all so called $n - 1$ contingencies and these constraints together form the constraints for the auction problem.

FTR market participants submit their benefit functions to the auctioneer. The objective of the auction is to maximize FTR revenues which is the same as maximizing the aggregate benefit function of the buyers. This is a form of sealed-bid, divisible good, uniform price auction. This auction accommodates multiple units as the market clears bids for FTRs involving different sets of nodes at once. In the PJM and the NYISO, participants commit a single quantity and bid price (PJMeFTR 2007), much like the tranches bid into the NZEM. The prices are set to the marginal clearing bids for each FTR.

In the literature (e.g. (Biskas, Ziogos, and Bakirtzis 2007) and (Deng, Oren, and Meliopoulos 2010),) the FTR simultaneously feasible auction (FTR-auction) is commonly defined using the concept of the power transfer distribution factor (PTDF) matrix. In the next subsection, we will formulate the FTR-auction, for the point-to-point obligation FTRs that uses the flow balance constraints, much like the EDP constraints, but is equivalent to the PTDF formulation.

2.1.1 Mathematical Formulation of the FTR Simultaneous Feasibility Auction

In this subsection we will present a formulation for the simultaneously feasible FTR auction for balanced point-to-point obligation FTRs. This model can easily be extended to include unbalanced FTRs (as well as option FTRs and reserved transmission rights).

$$
\begin{array}{lll}
\text{TRA-ND: maximize} & \sum_l \sum_{i,j} \beta^l_{ij}\tau^l_{ij} & \\
\text{subject to} & g_i(f_c) = \sum_l (\sum_{j\neq i} \tau^l_{ij} - \sum_{k\neq i} \tau^l_{ki}) & \forall c \in C \quad \forall i = 1, 2, \cdots, n \\
 & f_c \in U_c & \forall c \in C \\
 & 0 \leq \tau^l_{ij} \leq T^l_{ij}. &
\end{array}
$$

Here

- β^l_{ij} and T^l_{ij} denote respectively the bid price and quantity for the lth FTR with downstream node j and upstream node i.
- τ^l_{ij}, the decision variable, is the total amount of FTR l awarded between nodes i (upstream) and j (downstream).
- q_i is the net injection/withdrawal at node i as a result of awarding τ^l_{ij} FTRs.
- K_c denotes the vector of line capacities for the lines in the transmission network for contingency c.
- $g_i(f_c)$ is a function that maps the flows to injection/withdrawals and can include various forms of losses.

Note that $c \in C$ denotes the index of a contingency and f_c and U_c are respectively the flow and the electricity transmission constraints under contingency c.

Let π^c_i denote the optimal dual for constraint i, in contingency c in the first set of constraints in TRA-ND, that is the flow balance constraints. Then the market clearing price of the FTRs with upstream node i and downstream node j is defined as the difference $\sum_c \pi^c_j - \pi^c_i$ see e.g. (Biskas, Ziogos, and Bakirtzis 2007) and (PJMeFTR 2007).

As evident from either the TRA-ND or TRA-PTDF formulation, the FTR simultaneous feasibility auctions have embedded in them the transmission network constraints. Hence similar to the economic dispatch problem, they suffer from some peculiarities caused by the transmission network constraints. In the next subsection, we will attempt to demonstrate this with a small example.

2.2 Properties of the FTR Simultaneous Feasibility Auction

In this section we will provide a small illustrative example that explores the properties of FTR simultaneous feasibility auctions.

Example, two nodes. We start with a simple two node example. Consider a network consisting of two nodes (nodes 1 and 2 as depicted in Figure (2) and a 100MW line that links these nodes. Suppose that there is a bid for 99MW of FTR from node 1 to node 2, at price \$10.00. The FTR simultaneous feasibility auction will solve the optimization problem Ex-2-node.

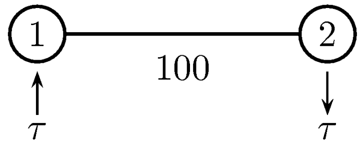

Figure 2: FTR over a simple 2 node transmission network.

$$
\begin{array}{lll}
\text{Ex-2-node:} & \text{maximize} & 10\tau \\
& \text{subject to} & \tau - f_{12} = 0 \quad [\pi_1] \\
& & f_{12} - \tau = 0 \quad [\pi_2] \\
& & f_{12} \leq 100 \quad [\eta^+] \\
& & -f_{12} \leq 100 \quad [\eta^-] \\
& & \tau \leq 99 \quad [\lambda] \\
& & \tau \geq 0.
\end{array}
$$

The optimal solution to this problem is given by $\tau = f_{12} = 99, \lambda = 10, \eta = 0$, and $\pi_1 = \pi_2$. This means that the clearing price of the FTR from node 1 to node 2 is zero (which is also the clearing price of the counterflow FTR going from node 2 to node 1). On the other hand if the there was a bid for 101MW of FTR from node 1 to node 2, at the same price of \$10.00, problem Ex-2-node would change slightly and the fourth constraint would be replaced by $\tau \leq 101$. This change would in turn change the solution to $\tau = f_{12} = 100, \lambda = 0, \eta = 10$, and $\pi_1 - \pi_2 = 10$. This would of course mean that the clearing price of the FTRs from node 1 to node 2 is now \$10.00. This is a byproduct of the transmission constraint, namely the capacity on the line from node 1 to node 2. When the volume of bids into the FTR auction is small, in this case less than the available capacity (100 MW) to be sold, the clearing price is well below what the participants are willing to pay. This is a feature of this uniform price auction that incorporates network constraints through simultaneous feasibility constraints.

3 Theoretical Results on the Efficiency of FTR Simultaneous Feasibility Auction

Deng et. al. (Deng, Oren, and Meliopoulos 2010) perform a theoretical analysis on current FTR markets and demonstrate that FTR markets enforcing the simultaneous feasibility constraints have inherent inefficiencies in the sense that auction clearing prices do not reflect expected nodal price differences. Their paper is motivated through empirical observations that in the New York ISO's TCC market, the clearing prices of TCC resulting from a simultaneous feasibility auction, differ significantly and systematically from the realized congestion revenues that determine the accrued payoffs of these rights (see e.g. (Siddiqui et al. 2005) and the discussion in the next section). Their model demonstrates that this inefficiency is not the result of lags in price discovery, rather the byproduct of the auction mechanism and the fact that cleared quantities of FTRs in the auction at all nodes is bounded (this is the case as the bid volumes for different FTRs is clearly bounded). They start with a premise where the FTR bidders are risk neutral. They further assume that the bidders have perfect foresight (i.e. know the expected nodal price differences,) and they bid in at these prices. They show that the FTR auction can produce clearing prices that are different from the expected prices.

To make this clear, we have investigated an small example that will explain the effect. Consider the network depicted below with three nodes and two lines. Note that there are two contingencies. In the first the capacity of the line linking nodes 2 and 3 is 200 MW and in the second, the capacity of this line reduces to 50MW. In this simple model, demand bids and supply offers remain the same in the two contingencies. The demand bid and the supply offers are all linear functions indicated on the diagram. We will assume that the two contingencies are equally likely in our model. We have solved the conventional EDP market clearing problem in contingency (a) and (b) and have reported the clearing prices and quantities in Tables 1 and 2 respectively.

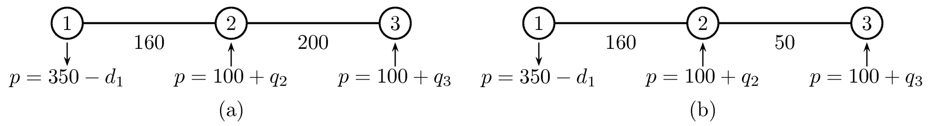

Figure 3: FTRs over a 3 node linear transmission network.

	(a)	(b)	$E[\pi]$
π_1	190.0	200.0	195.0
π_2	180.0	200.0	190.0
π_3	180.0	150.0	165.0

Table 1: Prices

	(a)	(b)	Ave
d_1	160.0	150.0	155.0
q_2	80.0	100.0	90.0
q_3	80.0	50.0	65.0

Table 2: Injections / Offtakes

Note that $E(\pi_1 - \pi_2) = \$5.00$ and $E(\pi_2 - \pi_3) = \$25.00$. The flows in each contingency scenario are provided in Table 3 below. Suppose now that the FTR auction participants are risk neutral and have perfect information about the price differences (namely they know that $E(\pi_1 - \pi_2) = \$5.00$ and $E(\pi_2 - \pi_3) = \$25.00$. This would mean that all participants would bid \$5.00 per MW for FTRs from node 2 to node 1 and all participants would bid \$25.00 per MW for FTRs from node 3 to node 2. If we now suppose that the total amount of FTRs bid in the FTR auction is the same as the average line flows, namely 155 MW FTR from node 2 to node 1 and, 65 MW FTR from node 3 to node 2, then the FTR market clearing problem

	(a)	(b)	Ave
f_{21}	160.0	150.0	155.0
f_{32}	80.0	50.0	65.0

Table 3: Flows

becomes.

$$\begin{aligned} \max \quad & 5q_{21} + 25q_{32} \\ \text{s.t.} \quad & d_1 = q_{21} \\ & q_2 = q_{21} - q_{32} \\ & q_3 = q_{32} \\ & q_2 + q_3 \leq 160 \\ & q_3 \leq 200 \\ & q_3 \leq 50 \\ & 0 \leq q_{21} \leq 155 \\ & 0 \leq q_{32} \leq 65 \end{aligned}$$

The optimal solution to this problem is given by

$$q_{21} = 155, \quad q_{32} = 50,$$

with FTR clearing prices of \$25.00 for the FTRs from node 3 to node 2 and \$0.00 for FTRs from node 2 to node 1. Note that this is a similar effect to that already discussed in the two node example in section 5.2. The average flow on the line from node 2 to node 1 is 155 MW which is strictly less than the capacity of that line (which does not vary in either contingency). Therefore, the price of FTRs for this line will clear at \$0.00, which is different from the average nodal price difference between nodes 2 and 1.

Deng et al. assert that when FTRs serve primarily as hedging instruments, bid quantities for FTRs tend to be close to expected transaction volumes and there are many point-to-point FTR pairs. Such a large range will have the effect (through the market clearing mechanism that embeds network effects) of imposing quantity limits on certain FTR awards which will cause the prices to deviate from the initial bid prices. They state that in more speculative markets where there are fewer FTR types and FTR quantities exceed hedging needs, the clearing prices are more likely to be close to efficient prices.

The following theorem demonstrates that although in the realistic sized examples provided by Deng et al. and in our simple illustrative examples the FTR auction clears inefficiently, there is incentive to correct this inefficiency through increasing the bid volume.

Theorem 1. *Consider the simultaneous feasibility FTR auction problem over any network where the bids for FTR prices are expected nodal price differences. Suppose that we*

- *solve the auction problem,*
- $(\forall i)$ *and* $(\forall j)$, *if* $\pi_j - \pi_i < \beta_{ij}$ *then raise* T_{ij} *by 1 MW and go to 1.*

Then we will stop in a finite number of iterations with the final clearing prices equal to the bid prices i.e. $\pi_j - \pi_i = \beta_{ij}$.

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