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Revenue Adequacy, Shortfall Allocation and Transmission Performance Incentives in FTR/FGR Markets

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Abstract

We examine the issue of revenue adequacy in Financial Transmission Rights (FTR) Markets and address two questions: a) How should revenue shortfalls in FTR markets be assigned to market participants? and b) How can active participation by transmission owners in FTR markets incentivize transmission performance through incremental and long term investment? In particular we focus on the possibility of short positions by transmission owners on financial Flowgate Rights (FGRs). Such positions would allow their holders to capture some of the FTR auction revenues in exchange for assuming liability for the corresponding FTR market revenue shortfall, which can be avoided through improvements in line ratings.

Keywords - *Financial Transmission Rights (FTR); Flowgate Right (FGR); Revenue Adequacy; Performance incentives; Transmission investment.*

Introduction

The prevalent market mechanism for defining transmission rights in North American restructured electricity markets is through financial instruments that enable energy traders to hedge congestion risk. The underlying quantities for such instruments are either Locational Marginal Prices (LMP) or shadow prices on transmission flowgates which are determined as part of an Optimal Power Flow (OPF) calculation. There are three prevalent forms of financial transmission rights whose settlements are based on the above underlying quantities:

- FTR Obligations - Holder is entitled to receive or obligated to pay nodal price difference between designated locations per MW denomination
- FTR Options - Holder is entitled to receive the nodal price difference between designated locations per MW denomination if that difference is positive but can walk away if it is negative.
- FGR - Holder is entitled to the shadow price on a specific congested link in the designated direction per MW denomination.

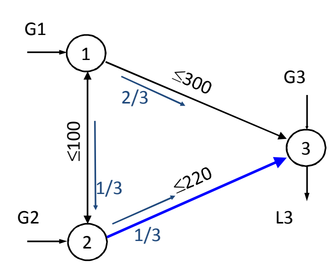
FTRs defining point to point financial transmission rights have been first introduced within a general framework of contract networks by Hogan [1] and have been widely adopted in the US as an integral part of the nodal market designs implemented by the various independent system operators. Flow based transmission rights (financial or physical) have been first introduced in a seminal paper by Chao and Peck [2]. The potential use FGRs, which are financial flow based rights, as substitutes or complements to FTRs has been discussed in [3],[4], [5] and in numerous follow-up papers. However, FGRs, are rarely used in today's markets since energy traders prefer FTRs that are more suitable for hedging point to point congestion risk. Specificall, a bilateral energy transaction of X MW from node A to another node B in the network is exposed to congestion risk between the two location and is liable for a congestion charge that equals to the difference of LMPs between the two node. That charge is equivalent to the net cost resulting from selling the power at node A and buying it back at node B at the respective nodal prices. A trader can offset such a congestion charge by holding an FTR from node A to B for X MW which entitles him to the nodal price difference between node B and node A time X. Hence the FTR payoff exactly equals the congestion charge.

Conceptually, however, FTRs and FGRs are equivalent due to the following fundamental relationship between nodal price differences and flowgate shadow prices (see [3]):

$$N_k - N_i = \sum_{\text{all flowgates j}} SP_j * PTDF_{ik,j}$$

Where N_i are the nodal prices, SP_j the shadow price on flowgate j and $PTDF_{ik,j}$ is the power transfer distribution factor on flowgate j due to a transaction from node i to k. Given this fundamental relationship a point to point FTR obligation may be viewed as a portfolio of FGRs weighted by the corresponding PTDFs. Hence a trader could achieve the same protection against congestion charges provided by an FTR by buying the equivalent portfolio of FGRs. To illustrate consider the three node network in Fig. 1:

Figure 1: Three node example



Suppose that G1 has a bilateral contract with L3 to deliver 150MW and wishes to hedge the contract against congestion charges. This can be done by procuring 150MW FTR from node 1 to 3. In real time the congestion rent charged to the bilateral transaction is the nodal price difference per MW which amounts to $150 \cdot (N_3 - N_1)$ and that is also the settlement payment for the 150MW FTR from node 1 to 3. Thus the FTR payments exactly offsets the congestion charge. Alternatively, the bilateral transaction can be hedged afainst congestion by procuring a portfolio of flowgate rights as follows: 100MW FGR on line 1to 3, 50MW FGR on line 1 to 2 and 50MW FGR on line 2 to 3. Each FGR is paid in real time the corresponding shadow price per MW. Assume that only the line 2 to 3 is congested then the shadow price on the other two lines is zero and the settlement payment for the above FGR portfolio is $50 \cdot SP_{23}$ but from the above relationship between nodal prices and shadow prices on transmission lines we know that $N_3 - N_1 = 1/3\, SP_{23}$. Hence the settlement payment for the FGR portfolio is the same as for the FTR from node 1 to 3 both of which equal the congestion charge for the bilateral transaction.

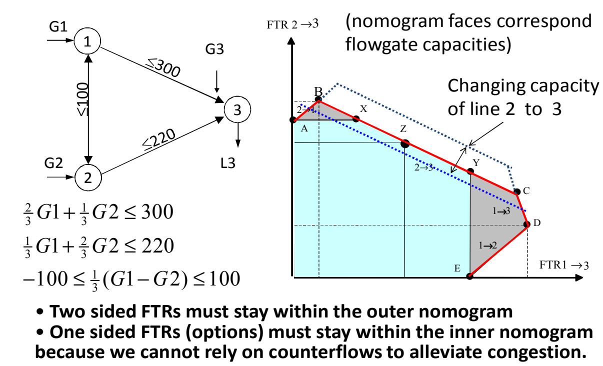
Arguments in favor and against employing FGRs in practice as hedges against congestion risk can be found in [3] and [4]. In our subsequent discussion we will only exploit the conceptual interpretation of FTRs as an FGR portfolio.

Hogan [1] has shown that if the outstanding FTRs satisfy a “simultaneous feasibility test” (SFT) and the network topology is fixed then the FTR market is ”revenue adequate”. Revenue adequacy means that congestion revenues and merchandising surplus collected by the system operator from bilateral transactions and local sales and purchases at the LMPs, will cover the FTR settlements. The SFT requires that if all the FTRs were exercised simultaneously as physical bilateral transactions then the transmission flow constraints would not be violated. In FTR auctions bidders submit bids for specific FTRs and the ISO selects winning bids by treating FTR bids as proposed schedules using a security constraint OPF that maximizes the FTR auction revenues. These constraints are also imposed if any portion of the FTRs is being allocated based on historical use or other allocation criteria. As mention above, the virtual “FTR operating point” corresponding to simultaneous bilateral schedules replicating all outstanding FTRs must meet all security and flow constraints i.e. the grid must be able to support all the bilateral transactions covered by the FTRs. The FTR operating point may differ, however, from real time dispatch but if the topology hasn’t changed it represents a feasible dispatch (and if the nomogram is convex) then the congestion revenues will be sufficient to cover the FTR settlements.

Revenue Adequacy

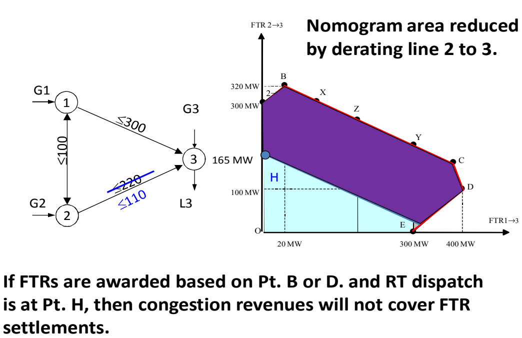
Flowgate capacity ratings will affect the feasible SFT nomogram as illustrated in Fig. 2 below for a three bus DC network.

Figure 2: Feasibility region of FTR options and obligations and the effect of flowgate capacity rating



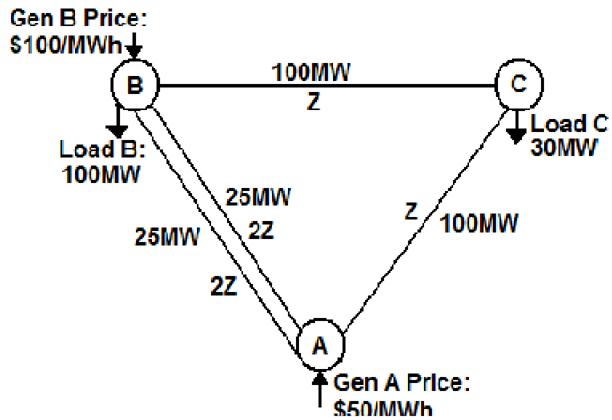
Consequently, if in real time operation, a flowgate rating is decreased from what was assumed in the SFT or if the flowgate failed due to a contingency then, the FTR operating point may not be feasible in the real dispatch topology as illustrated in Fig. 3. In such a case a revenue shortfall may occur, i.e., the congestion rents that are based on the real time LMP differences may not suffice to cover the settlements to all outstanding FTRs.

Figure 3: The effect of derating flowgate capacity



To illustrate such revenue shortfall more explicitly consider a three node example introduced in [6] and shown in Fig. 4. In this example FTRs are allocated based on an SFT which assumes the depicted topology. In particular 60MW FTR obligations from node A to B and 30MW FTR obligation from node A to C have been sold through an auction (or allocated by any other means).

Figure 4: Revenue adequacy example

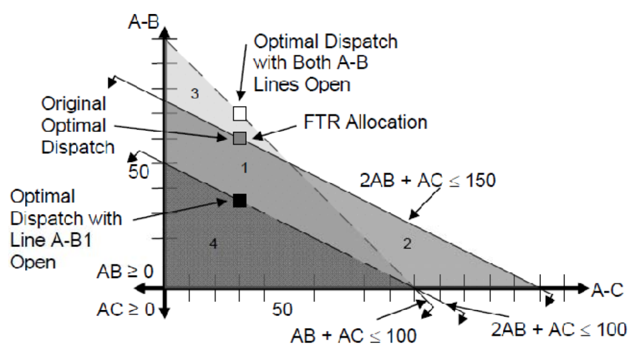


The feasible region for the SFT is characterized by the set of linear inequalities:

$$-50 \le \frac{2}{3}AB + \frac{1}{3}AC \le 50$$
$$100 \le \frac{1}{3}AB + \frac{2}{3}AC \le 100$$
$$-100 \le \frac{1}{3}AB - \frac{1}{3}AC \le 100$$
$$-100 \le AB + AC \le 100$$
$$-100 \le AB \le 100$$

This region is illustrated in Fig. 5 as the triangle consisting of areas 1, 2 and 4. The outstanding FTRs represent a point on the boundary of the feasible region (depicted by the gray square) and hence they satisfy the SFT for this topology.

Figure 5: Feasible region for different topologies



If the topology doesn't change then the optimal dispatch coincides with the FTR allocation and hence the corresponding congestion revenues exactly cover the payments to FTR holders. Suppose, however, that in operation one of the lines between node A and B fails. Such a contingency will shrink the feasible region to area 4 in Fig. 5 which is represented by the inequalities:

$$-25 \le \frac{1}{2}AB + \frac{1}{4}AC \le 25$$
$$-100 \le \frac{1}{2}AB + \frac{3}{4}AC \le 100$$
$$-100 \le \frac{1}{2}AB - \frac{1}{4}AC \le 100$$

Thus, the outstanding FTRs are no longer simultaneously feasible under the new topology.

The optimal dispatch under above contingency is represented by the black square in Fig. 5. Tables 1, 2 and 3 below show that the congestion revenues corresponding to this dispatch fall short of covering the settlement payments to the FTR holder. In this case the contingency affected the generators' output and flows but did not affect the LMPs and hence the FTR payments. Specifically, the congestion revenues dropped from $3,750 to $2,500 while the FTR settlement remains $3,750 resulting in a shortfall of $1,250.

Table 1: Optimal dispatch results with all lines in

Bus	Gen Pg	LMP	Gen Cost	Trans-action	MW	Cong. Rent
A	90MW	$50/MWh	$4,500	A – B	60MW	$3,000
B	40MW	$100/MWh	$4,000	A – C	30MW	$750
C	0MW	$75/MWh	$0	**Congestion Rent:**		**$3,750**
Total Generation Cost:			**$8,500**			

Table 2: Optimal dispatch results with one line A-B out

Bus	Gen Pg	LMP	Gen Cost	Trans-action	MW	Cong. Rent
A	65MW	$50/MWh	$3,250	A – B	35MW	$1,750
B	65MW	$100/MWh	$6,500	A – C	30MW	$750
C	0MW	$75/MWh	$0	**Congestion Rent:**		**$2,500**
Total Generation Cost:			**$9,750**			

Table 3: FTR settlements

Source to Sink:	FTR Quantity:	FTR Settlements (All lines in)	FTR Settlements (One line A-B out):
A to B	60MW	$3,000 (LMP gap: $50/MWh)	$3,000 (LMP gap: $50/MWh)
A to C	30MW	$750 (LMP gap: $25/MWh)	$750 (LMP gap: $50/MWh)
Total FTR Settlements:		**$3,750**	**$3,750**

Suprisingly, revenue adequacy can be restored and generation cost reduced in this case by switching off the other line between nodes A and B. The feasible region corresponding to the topology with both lines between node A and B out is defined by the constraint:

$$AB + AC \le 100$$

Since both A to B and A to C transactions must share the line between A and C. Hence, the feasible region is now represented by the triangle consisting of areas 1,3 and 4 in

Fig. 5 whereas the optimal dispatch moved from the black rectangle to the white rectangle. Furthermore, the gray rectangle representing the outstanding FTRs is now within the feasible region and can, therefore, be interpreted as a suboptimal feasible dispatch. Since an optimal dispatch solution also maximizes congestion rents (by duality theory of linear programming), it follows that the congestion rents exceed the FTR settlements which equal to the congestion rents corresponding to a feasible suboptimal dispatch. The above observations are verified numerically by the results in Tables 4 and 5. The optimal dispatch results with both lines between node A and B out are summarized in Table 4 and the corresponding FTR settlements are given in Table 5. We note that generation cost dropped to $8000 which is below the optimal dispatch with all lines in, while congestion revenues increased to $5,000 which is sufficient to cover the $4,500 FTR settlement payments.

Table 4: Optimal dispatch results with two lines A-B out

Bus	Gen Pg	LMP	Gen Cost	Trnsc	MW	Cong. Rent
A	100MW	$50/MWh	$5,000	A – B	70MW	$3,500
B	30MW	$100/MWh	$3,000	A – C	30MW	$1,500
C	0MW	$100/MWh	$0	**Congestion Rent:**		**$5,000**
Total Generation Cost:			**$8,000**			

Table 5: FTR Settlements with the two lines A-B out

Source to Sink:	FTR Quantity:	FTR Settlements (Both lines A-B Open):
A to B	60MW	$3,000 (LMP gap: $50/MWh)
A to C	30MW	$1,500 (LMP gap: $50/MWh)
Total FTR Settlements:		**$4,500**

Allocating Revenue Shortfalls

When a revenue shortfall occurs, i.e. congestion revenues cannot cover the settlement payments to FTR holders, the system operators must make up the difference. The various approaches adopted by system operators in the US for addressing such revenue shortfalls include:

- Full payment to FTRs based on nodal prices and uplift of the shortfall to sellers or buyers of energy (full funding approach)
- Prorate settlement to all FTRs to cover shortfall ("haircut" approach)
- Intertemporal smoothing of congestion revenue accounting by carrying over revenue surpluses and shortfall over an extended time period.
- Prorate settlement to FTRs based on impact of derated flowgates
- Full funding of FTRs and assignment of shortfall to owners of derated flowgates.

The first three alternatives socialize the cost of derated lines to energy sellers or buyers or to the FTR holders or across time periods. In the extreme case when a derated line is radial such socialization is vulnerable to gaming. An FTR holder on a derated but underutilized radial line has the incentive to congest that line though fictitious transactions in order to capture FTR revenues. The last two alternatives, which we advocate in this paper, directly assigns shortfalls to users or owners of derated flowgates. An important motivation for such an approach is to prevent potential gaming through overscheduling intended to induce congestion that will increase the payoff on certain FTRs. To illustrate such direct assignment consider the three node example in Fig. 1. In that example 1 MW FTR from node 1 to 3 contains 1/3 MW flow on line 2 to 3, whereas 1 MW FTR from node 2 to 3 contains 2/3 MW flow on line 2 to 3. Thus, if line 2 to 3 is derated by 50% the congestion revenue shortfall will be 110 times the shadow price SP_{23} on line 2 to 3. This shortfall can be assigned to the line owner while preserving full funding of the outstanding FTRs. Alternatively it can be assigned to the FTRs by reducing their settlement payment in accordance to the proportion of the derated line flow that they contain. Specifically since the capacity of line 2 to 3 was reduced by 50%, The payment to a 1 MW FTR from node 1 to 3 is reduced by 0.5x(1/3)x SP_{23} and the payment to a 1 MW FTR from node 2 to 3 is reduced by 0.5x(2/3)x SP_{23}. The SFT requires that the number of FTRs from node 1 to 3 times 1/3 plus the number of FTRs from node 2 to 3 times 2/3 does exceed the thermal limit of line 2 to 3 which is 220MW (and it equals to that limit when the shadow price SP_{23} is positive.) Hence, the reductions of FTR settlement payments above adds up exactly to 110x SP_{23} which is the revenue shortfall due to the derating of line 2 to 3.

Consider now the case when more than one line is derated. Suppose that line 2 to 3 is derated by 50% and line 1 to 3 is derated by 20%. Direct assignment the of revenue shortfall will again reduce the settlement payments to each FTR based on its flow share on each derated line. Thus payments to 1 MW FTR from node 1 to 3 is reduced by 0.5x(1/3)x SP_{23} +0.2x(2/3)x SP_{13}. Likewise payments to 1 MW of FTR from node 2 to 3 is reduced by 0.5x(2/3)x SP_{23} +0.2x(1/3)x SP_{13}. An intuitive analogy to the above approach is to think of FGRs as stocks and of FTRs as mutual funds which contain the various FGRs in proportions reflecting the corresponding PTDFs. When a line is rerated by 50% it is equivalent in our analogy to a stock loosing half its value. In the financial analogy it is natural that when a stock loses part of its value then the different mutual funds containing that stock will be impacted in proportion to their holdings of that stock. It would seem unreasonable to suggest that the loss of a stock would be born equally by all mutual funds offered by a brokerage house regardless of the holdings of the stock in each fund. Likewise it is natural and fair to allocate the revenue shortfall due to derating of a line according to the flow impact of each FTR on the derated line.

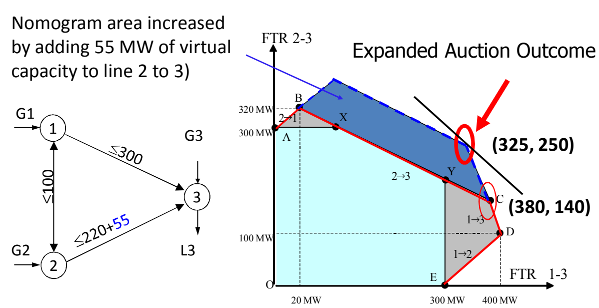
Expanding the FTR Feasible Region via Short FGRs

While derating lines capacities reduces the feasible set of FTRs that the network could support without revenue shortfalls, increasing line capacity ratings will increase the set of FTRs that can be awarded in the auction as shown in Fig. 6. Such an increase could result from a physical change in line capacity due to an upgrade of a line or improved maintenance. Alternatively, an increase in line capacity used for the purpose of the SFT can be "virtual" and supported by short positions on FGRs, just as an increased number of available FTRs between two points can be underwritten by counterflow commitments. A short position on an FGR amounts to an obligation to either increase the flowgate capacity or underwrite the settlement cost of the added FTRs. The holder of a 1MW short FGR position on a particular line is paid the shadow price on that line in the SFT power flow calculation and is liable for the shadow price on that line in real time. The payment received by such a short position holder in the FTR auction is financed by the revenue from the additional FTRs that can be sold due to the increase in the SFT feasible nomogram.

The real time settlement paid by the short FGR holder supplements the congestion revenues and will cover any FTR revenues shortfall resulting from the oversold FTRs. If the line for which the short FGR position was issued is not congested in real time then the holder of that position gets to pocket the auction revenue for underwriting that position. To illustrate, suppose that the auction clearing price on both FTRs depicted along the axis in Fig. 6 (Node 2 to 3 and node 1 to 3) is \$10/MW/hour, then the corresponding shadow price on line 2 to 3 is also \$10/MW/hour. A short position of 55MW on line 2 to 3 will earn its underwriter \$550/hour. Such a short position expands the feasible region in the SFT as shown in Fig. 6 and changes the results of the FTR auction clearing so that the number of FTRs awarded from node 2 to 3 increase from 140MW to 250MW while the number of FTRs awarded from node 1 to node 3 is reduced from 380 to 325. In this particular case the expansion of the feasible region did not change the FTR clearing prices only their awarded quantities. Thus the net gain in FTR auction revenue is 10x(250-140)+10x(325-380)=\$550 which is exactly the amount paid by the auctioneer for the 55MW short FGRs. In real time the underwriter of the short FGRs is liable for 55x SP_{23} which should cover any revenue shortfall resulting for the incremental FTRs awarded against the short FGR position. However, if the line 2 to 3 turns not to be congested SP_{23} is zero and no revenue shortfall occurs so that the short FGR underwriter got to pocket the short position income.

Short FGR positions can be assumed by any entity that wishes to bet against certain lines being congested. However, such instruments are ideally suited for transmission owners (TOs) who are in a position to upgrade the line or maintain it so as to increase its real time rating. Thus, short flowgate positions provide incentives for incremental improvements and maintenance (e.g. vegetation control) that can enhance real time transmission capacity. If a line is not binding in real time then the TO retains the auction income for the short position taken. Similarly, short positions on long term flowgate rights can finance planned upgrades and investments that will alleviate congestion on the shorted flowgates while enabling the ISO to issue long term FTRs against such upgrades.

Figure 6: Expanding FTR Feasibility with Short FGR Positions



Like in every performance based incentive scheme, performance must be measured and verified against a credible and stable yardstick (e.g. PBR scheme for NGC in the UK). TOs should get assurances that they will not face a moving target and improvements they make will not change the nominal line rating used in subsequent FTR auctions. Furthermore, active participation by TOs in FTR trading must be regulated to insure correct incentives (e.g. long positions by TOs should not be allowed since they create incentives to restrict flow).

Conclusion

Just as point to point FTRs provide a convenient hedge against congestion charge risk for point to point energy transactions, FGRs are convenient instruments for managing flowgate capacity risk and reward investment in such capacity. When a revenue shortfall occurs allocating the losses based on the imbedded FGR content of various FTRs or directly to the TO of the affected flowgate, eliminates socialization that can cause inefficiencies and gaming. Conversely FGR short position that expand possible FTR awards provide a useful means for financing investment and reward performance that improves flowgate ratings. These positions also allow private parties to underwrite FTR revenue shortfalls due to flowgate capacity risk. Such activities, however, must be carefully regulated and monitored to avoid perverse incentives and abuses.

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