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Merchant Electricity Transmission Expansion: A European Case Study

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Abstract

We apply a merchant transmission expansion model to the trilateral market coupling arrangement among the Netherlands, Belgium and France as a generic example, and note that it can be applied to any general market splitting or coupling of different national power markets in Europe. In this merchant transmission expansion framework, the system operator allocates financial transmission rights (FTRs) to investors in transmission expansion depending on their preferences and revenue adequacy. We study the case for FTRs in Europe including incentives for investors in transmission expansion.

Resumen

Aplicamos un modelo de mercado para la expansión de la transmisión eléctrica al acuerdo trilateral de "emparejamiento de mercado" (market coupling) entre los Países Bajos, Bélgica y Francia, como un ejemplo genérico. Nótese que este modelo también puede ser aplicado a cualquier emparejamiento o partición de mercado (splitting) para diferentes mercados eléctricos nacionales en Europa. En este contexto de expansión de la transmisión por medio del mercado, el operador del sistema asigna Derechos Financieros de Transmisión (FTRs) a los inversionistas dependiendo de sus preferencias y la condición de "ingresos adecuados" (revenue adequacy). Estudiamos el caso para FTRs en Europa incluyendo los incentivos para los inversionistas en la expansión de la transmisión.

Introduction

In this paper we study the case for FTRs in Europe including incentives for investors in transmission expansion. We apply a merchant transmission expansion model to the trilateral market (TLC) coupling arrangement among the Netherlands, Belgium and France as a generic example. Within a merchant framework, the system operator allocates financial transmission rights (FTRs) to investors in transmission expansion depending on their preferences and revenue adequacy. We note that this mechanism can also be applied to any general market splitting or coupling of different national power markets in Europe.

Market coupling and flow-based congestion management methods in Europe

Prior to November 21, 2006, the cross-border trade among the Netherlands, Belgium and France was managed by explicit auctions. Now, the daily auctions accommodate a trilateral market coupling (TLC) arrangement (an implicit auction), and this redesign has resulted in more efficient trade and a single price for most time periods (APX, 2007). However, explicit auctions are still being used for annual and monthly transmission allocations. The TLC links prices with the three areas, and the areas themselves are coordinated through an algorithm that calculates imports and exports (APX, 2007). The three TSOs, RTE, ELIA and Tennet, remain responsible for the transmission capacity allocation and the implementation of the TLC results. The three exchanges, Powernext, Belpex and Apx, determine the market prices. Decoupling from the TLC arrangement of the three areas is also possible, in which case explicit auctions are then utilized.

Recently there has been some discussion in Europe about introducing FTRs as a component of the TLC, and about moving toward flow-based transmission and open/multilateral market coupling. The allocation of cross-border capacity is currently based on net transfer capacity (NTC). For the flow-based allocation mechanism, all regional commercial transactions would be converted into physical power flows at the critical branches by using the PTDF factors. Thus, power transfer distribution factors (PTDFs) and net border capacity (NBC) would substitute for the NTCs in the flow calculations. The PTDFs would account for physical electrical flow paths and maximize the use of transmission capacity subject to NBCs. A meshed network would make it more difficult to link the implicit and explicit auctions employed in the daily, monthly and annual auctions respectively.

An advantage of the flow-based method is that it can be differentiated between market coupling (implicit auctions) and coordinated explicit auctions. In market coupling, players submit bids for energy prices and transmission capacity, and in coordinated explicit auctions, players submit bids for transmission capacity prices. The flow-based congestion management methods would support FTRs by applying PTDFs. The PTDFs describe the amount of physical flow on a given interconnection that would be provoked by a requested commercial exchange between two countries or two control areas (or 'hubs') (ETSO, 2007). The two hubs do not necessarily need to be directly connected. In flow-based allocation, NTCs do not exist between two control areas. However, the maximum allowable flow and an estimate of the flow that is already present on certain branches are available prior to the allocation. The commercial transactions are no longer limited to the interconnections where they are reported, but they are converted into physical power flows by using a simplified representation of the network so that their impacts on third interconnections can be considered (thus ensuring overall security) Finally, flow-based transmission capacity allocation can be viewed as a supra-national approach because one centralized auction administrator optimizes and allocates all of the energy price bids and/or cross-border capacity bids.

In the implicit flow-based allocation, the influence of all price area imbalances is totaled for each critical branch and when the resulting physical flow is higher than what is available on a certain critical branch (*i.e.* the maximum allowed flow minus the flow that is already present prior to the allocation), the energy bid/offer with the lowest offered price per MW of the flow on the congested critical branch is the first to be reduced. In essence, a set of buying/selling bids is determined as providing the highest market value to the auctioned regional set of transfer capacities under the given constraints.

The objective of the explicit flow-based allocation procedure is not to reduce the differences between physical flows and commercial exchanges on a given critical branch, 'flow-gate' or tie line between two countries. For the implicit flow-based allocation an additional criterion necessary for the price area imbalances to define a unique set of cross-border commercial exchanges could be related to the difference between the cross-border commercial exchanges and the physical flows. Thus, the 'flow-based' allocation method may not necessarily reduce the difference between commercial exchanges and physical flows on tie lines between control areas. However, it will provide the means to allocate capacity to those bids which value it mostly in a given region subject to transmission capacity limits.

However, an additional criterion is needed to define a unique set among the infinity of possible sets of cross-border commercial exchanges translating the price area imbalances. This optimization problem can be solved as a linear program for which the simplified 'mathematical' description is as follows (ETSO, 2007):

a) **For an explicit flow-based allocation:**

$$\max \sum_i p_i q_i$$
$$0 \le q_i \le Q$$
$$PTDF \cdot q_i \le (F_{\max} - F_{ref})$$

p_i: bid price
q_i: allocated bid quantity
Q: bid quantity
Fmax: maximum flow
Fref: reference flow
control variable: allocated quantity

b) **For an implicit flow-based allocation:**

$$\max \sum_i b_i q_{bi} - o_i q_{oi}$$
$$0 \le q_{bi}$$
$$0 \le q_{oi}$$
$$PTDF \cdot (q_{bi} - q_{oi}) \le (F_{\max} - F_{ref})$$

b_i: bid price
o_i: offer price
q_{bi}: allocated bid quantity
q_{oi}: allocated offer
control variable: price area imbalance
The shadow price allows us to compute the marginal settlement prices.

Although there are no flow-based allocation operations in Europe, there is a dry-run implementation in the region of Central Eastern Europe (CEE) and a dry-run of coordinated auctions in the region of South Eastern Europe (SEE). A flow-based allocation mechanism is under development in the Central-Western European (CWE) region. When implicit auctions are introduced, the market design will be much like that of locational pricing where the nodes are individual countries. A refined model with several nodes per country could also be considered.[1]

TLC results

The TLC arrangement for the Netherlands, Belgium and France began operations on November 21, 2006. An analysis of the preliminary results (as of April 2007) already reveals several benefits (APX, 2007):

- Optimized use of cross-border transmission capacity among the three countries that supports increased imports and exports.
- Increasing liquidity on Belpex supports a stable price formation for the Belgian market.
- Increased price convergence and price stability generally (the three markets showed a common price 65% of the time)

Table 1 shows the development of the annual prices before and after the TLC arrangement.

TABLE 1. COUNTRY PRICES IN DIFFERENT YEARS

Country price (EUR/MWh)	Netherlands (APX)	France (Powernext)	Belgium (Belpex)
2004	31.35	28.14	NA
2005	52.30	46.73	NA
2006	58.13	49.36	45.69
2007	31.86	30.38	30.84

[1] ETSO (2007) mentions the following implementation issues:
Market related issues:

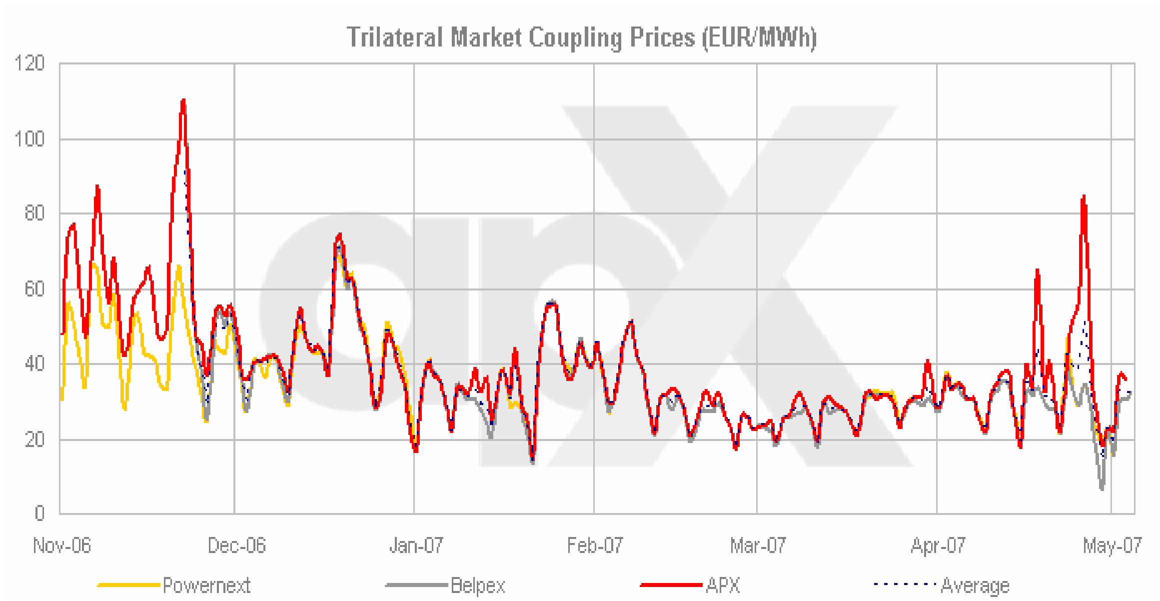
- Market transparency: In an NTC-based allocation mechanism, market players observe the NTC and submit their bids for capacity. When a flow-based transmission model is used for regional capacity allocation, the market players will themselves choose the most economically efficient cross-border trades. Thus, the flow-based method will reveal, in a transparent way, the location of the limiting constraint.
- Economic signals to market participants and the sharing of congestion income: Generally all bids in a coordinated flow-based allocation method compete with each other. Thus, low-priced bids between two uncongested control areas have to compete with, the high-priced bids between two congested control areas, according to their contribution to the congestion.
- Liabilities of TSOs and position of individual regulatory authorities: Any commercial transaction may use transmission capacity on each interconnection of the interconnected system. To avoid that any TSO offers no or very limited capacity, and thus blocking other transactions, there should be appropriate revenue distribution methods among TSOs and proper political, regulatory and TSO coordination.

The prices at APX were on average higher than the prices at Powernext before the introduction of the TLC while the Belpex price was introduced simultaneously with the TLC arrangement (see

figure). After the introduction of the TLC, the prices at APX and Powernext had a high correlation and all prices showed high integration.[2] However, even if the average prices are similar, the prices in certain hours may have a large differential and thus contribute to the optionality value of an interconnector. Trading over the interconnector has value in explicit auctions while the payoff is zero in implicit auctions.

The TLC arrangement was operated in decoupled mode on April 27 and 28, 2007 and the day-ahead cross-border capacity was allocated by an explicit auction for the NL-BE and BE-FR borders on the same days.

FIGURE 1. THE DAILY AVERAGE PRICE FOR TLC COUNTRIES (APX, 2007)



The annual explicit auctions provide us with information that reveals how market players value cross-border transmission capacity. The prices for 2007 are shown in Table 2. We observe that the TLC countries place the highest value on transmission capacity between Belgium and the Netherlands followed by Belgium-to-France. Thus it appears that the market players desire capacity from relatively lower priced France to the relatively higher-priced Netherlands. We can observe the same trend when the market players place the highest value on cross-border capacity from Germany to the Netherlands.

[2] In late April 2007, there were periods when prices at APX and Powernext were higher than at Belpex.

TABLE 2. PRICES OF CROSS-BORDER CAPACITY IN EXPLICIT AUCTIONS IN THE TLC AND IN GERMANY

Cross-border capacity price (€/MWh)	Year 2007 forward	Year 2007 backward
Belgium-to- Netherlands	0.11	3.46
Belgium-to-France	0.25	2.06
RWE TSO area-to-Netherlands	8.01	0.05
E.ON TSO area-to-Netherlands	8.32	0.03

Several long-awaited projects for new interconnectors to and from the Netherlands will expand the possibilities for Europe's market players:

- E.ON Netz plans to increase the interconnection capacity from Germany to the Netherlands by 550 MW (from 850 MW to 1400 MW) by October 2007; however, we note that during periods of increased wind power generation, the capacity could be temporarily limited and initially offered on a non- firm basis.
- The 700 MW NorNed cable between Norway and the Netherlands is expected to be fully operational by the end of October 2007.
- The 1000 MW BritNed cable between the Netherlands and the UK is expected to be fully operational after 2010.
- The German TSO RWE Transportnetz and the Dutch TSO TenneT signed an MoU regarding a new interconnector between their respective TSO areas that will increase transmission from the present 1000 MW to 2000 MW; it is expected to fully operational by 2013 at the earliest

The major motivation for constructing the NorNed cable is security of supply, since Norway is almost entirely dependent on hydro (99% hydro generation) and the Netherlands is predominantly thermal. In a normal hydrology year Norway could export peak load power to the Netherlands (prior to the TLC implementation, the Netherlands experienced higher peak prices than Norway), or conversely it could import off-peak power from the Netherlands which has lower off-peak prices due to a relative large share of CHP and must-run generation. In a dry year, Norway could import relatively more power. Norway's abundant hydro generation also provides greater flexibility including the provision of ancillary services.

Merchant transmission investment in Europe

The European approach to transmission expansion issues is spelled out in the EU Regulation on Cross-Border Exchanges in the EC electricity directive which became effective on July 1, 2004. The regulation requires:

- TSOs must establish coordination and information exchange mechanisms

- Publication of safety, operational and planning standards
- Non-discriminatory, market-based, no curtailment
- Use it or lose it principle
- Netting if technically possible
- Congestion revenue must be used for operation and investment (it is netted with regulated income)

Article 7 of the regulation provides the rules for scarce capacity on existing cross-border interconnectors; Article 6 (6) allows for new interconnectors to be exempted from regulation of the revenues of allocation of scarce capacity; and Articles 20 and 23 require (regulated) third-party access to the network (see Brunekreeft, 2003). In other words, the EU regulation allows unregulated merchant transmission investment (UMTI), provided a set of conditions is met; the following are the most significant:

- A new interconnector must enhance competition in the energy market.
- Following the unbundling requirements in the EU electricity directive, the interconnector should be legally unbundled from the TSOs, but ownership separation is not required.
- The exemption to UMTI normally applies to direct current (DC) lines, but exceptions are made for alternating current (AC) lines if DC technology is prohibitively costly

The European approach to UMTI may be suboptimal for (at least) two reasons. First, in a meshed AC network, a new line (financed by interconnector-based price differences) can be privately profitable but socially detrimental due to loop-flow effects. As argued by Bushnell and Stoft (1996) and Kristiansen and Rosellón (2006), this problem could be solved by rewarding the new line with a set of must-accept incremental financial transmission rights (FTRs) that will internalize such network effects. The set of incremental FTRs is determined by a central institution (TSO or ISO) running a power flow model.[3] As pointed out by Joskow and Tirole (2003), defining a set of incremental FTRs may internalize the network effects but could indicate a step away from the invisible hand. We note that using incremental FTRs requires an underlying system of locational marginal prices, but Europe has not yet implemented LMP. Along with Brunekreeft (2003a), we believe this justifies allowing UMTI to DC interconnectors of different systems. We also assert that because Europe already employs zonal pricing extensively, zonal pricing might possibly be considered as a simplified version of nodal pricing. Examples are Norway and Italy which have several internal price areas, and the majority of European countries which apply a single internal

[3] As discussed in ETSO (2006), TSOs should play an important role in the design and operation of FTR auctions. For instance, TSOs should define the types and duration of FTRs to be auctioned, ensure the technical simultaneous feasibility and revenue adequacy of the system, and implement a payback procedure for negative externalities generated by the transmission expansion projects (Kristiansen and Rosellón, 2006). Then, the goal of the TSO is to reach a balance in the trade-off between market facilitation and risk- sharing among parties so that sound price signals are sent to market participants.

price. To the extent that the network effects can be localized, deep connection charging (for e.g. network upgrades) can internalize the network effects. Moreover, an interconnector may be compared to a new power plant that also causes network effects.

The EU Regulation (Article 7.1) lists several criteria in order to qualify for exemption from regulation. The chief condition is that: "the investment must enhance competition in electricity supply". However, the *level* of competition is unclear: for example, on one side only or on both sides of the interconnector, or overall competitiveness. Another situation the EU Regulation does not address is what happens when demand elasticity is low (implying that the welfare gains from increased competition would be rather small). The EU Regulation appears vague about some important effects related to competition enhancement: increased competition may decrease regulatory costs that are not captured in the regulation; market power could induce excessive entry (and may incur additional regulatory costs to monitor); and finally, an implicit assumption of equal social weight for consumers and producers. As Brunekraft (2003) argues, the positive effects of competition will be higher when weights for consumers increase in the social welfare criterion.

It could be argued that the TSO is in the optimal position to offer FTRs because the risk of providing them correlates with the revenue from transmission congestion. However, TSOs normally undertake transmission capacity investments within a regulated framework and usually recover their investment costs through transmission tariffs. Conversely, merchant investors would require regulatory approval to undertake the types of investment discussed above.

Zonal pricing offers these favorable attributes:

- Higher resolution than zonal pricing might be difficult with physical transmission contracts.
- Zonal pricing is pragmatic rather than theoretically perfect.
- Arguably, fewer prices (zones or nodes) will increase liquidity in the current spot and forward markets; the markets will be integrated when there is no congestion

However, using it to simplify the current situation in Europe raises these concerns:

- The zonal pricing model itself involves a sub-optimal social welfare solution because it is an inaccurate representation of loop flows; thus, zonal pricing is not able to fully internalize all network effects since the network is modeled in a simplified manner.
- Since each country is responsible for its internal transmission constraints, this may result in a sub-optimal allocation of cross-border transmission capacity; thus there is a trade-off between the use of capacity for internal and international transmission.

- It is more difficult to locate the most- and least-congested areas and to support local investments

Financial transmission rights (FTRs)

During 2004 and 2005, there was increased interest in transmission risk hedging products for cross-border trade and congestion management on several occasions:

- In 2004 the European Commission included a reference to FTRs as a complement to auctions of forward physical transmission rights at the 11th Florence Regulatory Forum.
- In October 2004, regulators CNE (Spain) and CRE (France) included financial instruments in their final public consultation concerning the implementation of coordinated and market-based congestion management mechanisms.
- On January 1, 2005, the Italian regulator implemented an implicit auction scheme on the Italian side of the interconnection capacity (considering virtual zones for offers/bids from neighboring countries), and TERNA (the national grid company) assigned FTRs for zone-to-zone price volatility.
- In July 2005, the public consultation on the draft Guidelines on Congestion Management organized by ERGEG (European Regulators' Group for Electricity and Gas) and the discussions on September 1-2, 2005 at the 12th Florence Forum focused on the appearance of new risks as TSOs adapted the existing complex physical power system to the new market

An efficient implementation of forward transmission rights under meshed network conditions requires TSOs to provide a more elaborate, flow-based transmission model. A simultaneous feasibility test would maximize the value of the set of FTRs accepted under constraints of zonal PTDFs and transmission capacities. RTE *et al.* (2006) foresee a possible future introduction of FTRs. RTE also suggests that FTRs should be introduced under regulatory control and as demanded by the market. Likewise, appropriate risk-sharing and regulatory incentives are needed.

FTRs could assume several forms (APX, 2007):

- Market players could return capacity to the TSO for re-auctioning; the auction revenue they would receive could equal the market coupling price difference.
- A "use it or sell it" principle: the market players could schedule physically, or submit for financial revenue.
- An implicit auction; daily financial settlement would equal that of an explicit auction.
- Use of physical transmission capacity as an FTR.

- Re-trading FTRs

Merchant FTR allocation methodology

The following description is based on earlier work by Kristiansen and Rosellón (2006). This model studies optimal allocation of FTRs when the ISO reserves some FTRS (proxy awards) to resolve the negative externalities associated with transmission expansion projects. First, we review some of the model's major components. Consider the following economic dispatch model:[4]

$$\operatorname*{Max}_{Y,u\in U} B(d-g) \tag{1}$$

$$s.t.$$

$$Y = d - g, \tag{2}$$

$$L(Y,u) + \tau^T Y = 0 \tag{3}$$

$$K(Y,u) \le 0 \tag{4}$$

Where d and g are load and generation at the different locations. The variable Y represents the real power bus net loads, including the swing bus S ($Y^T = (Y_s, \bar{Y}^T)$). B(d-g) is the net benefit function,[5] and τ is a unity column vector, $\tau^T = (1,1,...,1)$. All other parameters are represented in the control variable u. The objective for Equation (1) includes the maximization of benefit to loads and the minimization of generation cost. Equation (2) denotes the net load as the difference between load and generation. Equation (3) is a loss balance constraint where $L(Y,u)$ is a vector that denotes the losses in the network. In equation (4), $K(Y,u)$ is a vector of power flows in the lines that are subject to transmission capacity limits. The corresponding multipliers or shadow prices for the constraints are $(P, \lambda_{ref}, \lambda_{tran})$ for net loads, reference bus energy (or loss balance) and transmission constraints respectively.[6]

The locational prices P are the marginal generation cost or the marginal benefit of demand that in turn equals the reference price of energy plus the marginal cost of losses and congestion. With the optimal solution (d^*, g^*, Y^*, u^*) and the associated shadow prices, the vector of locational prices

[4] Hogan (2002b) has shown that the economic dispatch model can be extended to a market equilibrium model where the ISO produces transmission services, power dispatch, and spot-market coordination, while consumers have a concave utility function that depends on net loads and on the level of consumption of other goods.

[5] Function *B* is typically a measure of welfare, such as the difference between consumer surplus and generation costs (see Hogan, 2002b).

[6] When security constraints are accounted for (n-1 criterion,) this is a large-scale problem, and its price anticipated contingencies through the security-constrained economic dispatch. In operations, the n-1 criterion can be relaxed on radial paths; however, doing the same in the FTR auction of large-scale meshed networks may result in revenue inadequacy. We do not use the n-1 criterion in our paper.

is:

$$P^T = \nabla C(g^*) = \nabla B(d^*) = \lambda_{ref}\tau^T + \lambda_{ref}\nabla L_Y(Y^*, u^*) + \lambda_{tran}^T \nabla K_Y(Y^*, u^*) \qquad (5)$$

If we ignore losses,[7] only the energy price at the reference bus and the marginal cost of congestion contribute to set the locational price.

FTR obligations[8] hedge market players against differences in locational prices caused by transmission congestion.[9] FTRs are provided by an ISO, and are assumed to redistribute the congestion rents. The payoff from these rights is given by:

$$FTR = (P_j - P_i)Q_{ij} \qquad (6)$$

Where P_j is the price at location j, P_i is the price at location i, and Q_{ij} is the directed quantity injected at point i and withdrawn at point j specified in the FTR. The FTR payoffs can take negative, positive or zero values.

A set of FTRs is said to be simultaneously feasible if the associated set of net loads is simultaneously feasible, that is if the net loads satisfy the loss balance and transmission capacity constraints as well as the power flow equations given by:

$$\begin{aligned} &Y = \sum_k t_k^f \\ &L(Y,u) + \tau' Y = 0, \\ &K(Y,u) \le 0 \end{aligned} \qquad (7)$$

Where $\sum_k t_k^f$ is the sum over the set of point-to-point obligations.[10]

If the set of FTRs is simultaneously feasible and the system constraints are convex,[11] then the FTRs satisfy the revenue adequacy condition in the sense that equilibrium payments collected by the ISO through economic dispatch

[7] In the PJM (Pennsylvania, New Jersey and Maryland) market design, the locational prices are defined without respect to losses (DC-load flow model); in New York the locational prices are calculated based on an AC-network with marginal losses.

[8] FTRs could be options with a payoff equal to max($(P_j - P_i)$ Q_{ij} ,0).

[9] See Hogan, 1992.

[10] The set of point-to-point obligations can be decomposed into a set of balanced and unbalanced (injection or withdrawal of energy) obligations (see Hogan, 2002b).

[11] This has been demonstrated for lossless networks by Hogan (1992), extended to quadratic losses by Bushnell and Stoft (1996), and further generalized to smooth nonlinear constraints by Hogan (2000). Philpott and Pritchard (2004) have shown that negative locational prices may cause revenue inadequacy. Moreover, in the general case of an AC or DC formulation to ensure revenue adequacy, the transmission constraints must satisfy optimality conditions (particularly if such constraints are convex, they must satisfy optimality); see O'Neill *et al.* (2002), and Philpott and Pritchard (2004).

will be greater than or equal to payments required under the FTR forward obligations.[12]

Now assume investments in new transmission capacity. The associated set of new FTRs for transmission expansion must also satisfy the simultaneous feasibility rule. In other words, both the new and old FTRs must be simultaneously feasible after the system's expansion. If we assume that T is the current partial allocation of long-term FTRs, then by assumption ($K(T,u)\leq 0$) is feasible. Now suppose there is to be a total possible incremental award, and that a fraction of the possible awards is reserved as proxy awards for the existing grid, and the remainder is provided to the incremental investor as representing the proportion that could only be awarded as a result of the investment. Let *a* be the scalar amount of incremental FTR awards, and $\hat{t}$ the scalar amount of proxy awards, and let δ be directional vector[13] such that $a\delta$ is the MW amount of incremental FTR awards and $\hat{t}\delta$ is the MW amount of proxy awards between different locations. Any incremental FTR award $a\delta$ should comply with the feasibility rule in the expanded grid. Hence, we must have $K^{+}(T+a\delta,u)\leq 0$, where K^{+} corresponds to the capacity of the expanded grid.

When certain currently unallocated rights (proxy awards) $\hat{t}\delta$ in the existing grid must be preserved, they will total $T+\hat{t}\delta$ when combined with the existing rights.[14] Then K^{+} should also satisfy simultaneous feasibility so that $K(T+\hat{t}\delta,u)\leq 0$, $K^{+}(T+a\delta,u)\leq 0$, and $K^{+}(T+\hat{t}\delta+a\delta,u)\leq 0$ for incremental awards $a\delta$. What is the best way to define proxy awards? One possibility is to define them as the "best use" of the current network along the same direction as the incremental awards.[15] This definition includes both positive and negative incremental FTR awards. The best use in a three-node network may be thought of as a single incremental FTR in one direction or a combination of incremental FTRs defined by the directional vector δ, depending on the investor preference. Hogan (2002a) has suggested defining "best use" as:

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[12] Revenue adequacy is the financial counterpart of the physical concept of availability of transmission capacity (see Hogan, 2002a).

[13] Each element in the directional vector represents an FTR between two locations; the directional vector may have many elements representing combinations of FTRs.

[14] Proxy awards are then currently unallocated FTRs in the pre-existing network that basically facilitate the allocation of incremental FTRs and help to preserve revenue adequacy by reserving capacity for hedges in the expanded network.

[15] Another possibility is to define every possible use of the current grid as a proxy award. However, this would imply that any investment beyond a radial line would be precluded, and that incremental awarding of FTRs might require adding capacity to every link on every path of a meshed network. The idea of defining proxy awards along the same direction as incremental awards originates from a proposal developed for the New Zealand electricity market by Transpower.

Preset proxy preferences (p)

$$
\begin{aligned}
&\hat{y} = T + \hat{t}\delta, \\
&\hat{t} \in \arg\max_{t} \left\{ \ \hat{t}p\delta \mid K(T + t\delta) \leq 0 \right\}
\end{aligned} \tag{8}
$$

In Hogan's proxy formulation, the objective is to maximize the value (defined by prices *p*) of the proxy awards given the pre-existing FTRs, and the power flow constraints in the pre-expansion network. In the investor preference formulation, the objective is to maximize the investor's value (defined by the bid functions for different directions, $\beta(a\delta)$) of incremental FTR awards given the proxy and pre-existing FTRs and the power flow constraints in the expanded network, while simultaneously calculating the minimum proxy scalar amount that satisfies the power flow constraints in the pre-expansion network.

Next, we analyze how to use this protocol to carry out an allocation of long-term FTRs that stimulates investment in transmission. We assume the preset proxy rule is used to derive prices that maximize the investors' preference $\beta(a\delta)$ for an award of MWs of a FTRs in direction δ. We then have the following auction maximization problem:

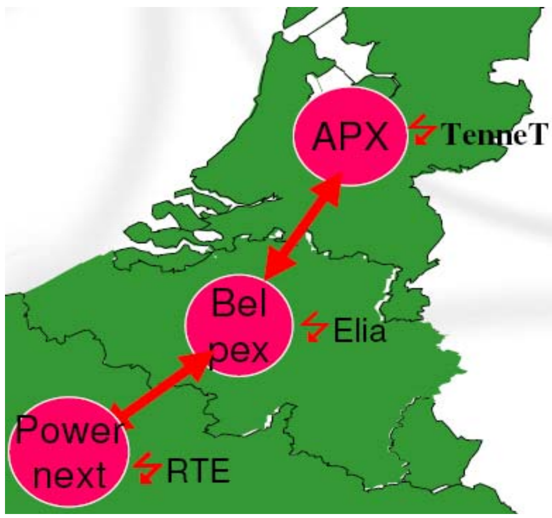
$$
\begin{aligned}
&\operatorname*{Max}_{a,\hat{t},\delta} \ \beta(a\delta) \\
&s.t. \\
&K^{+}(T + a\delta, u) \leq C^{+}, \\
&K^{+}(T + \hat{t}\delta + a\delta, u) \leq C^{+}, \\
&\hat{t} \in \arg\max_{t} \{ tp\delta \mid K(T + t\delta, u) \leq C \}, \\
&\|\delta\| = 1, \\
&a \geq 0.
\end{aligned} \tag{9}
$$

In this model, the investors' preference is maximized subject to the simultaneous feasibility conditions, and the "best use" protocol. The auction model is a nonlinear optimization problem of a "bi-level" nature. There are two optimization stages. Maximization is non-myopic since the result of the lower problem (first stage) depends on the direction chosen in the upper problem (second stage). Bi-level problems may be solved by first transforming the lower problem (*i.e.* the allocation of proxy awards) into a set of Kuhn-Tucker equations that are subsequently substituted in the upper problem (*i.e.* the maximization of the investors' preference). We can then understand the model as a Stackelberg problem although it is not intended to optimize the same type of objective function at each stage. For a detailed solution procedure, see Kristiansen and Rosellón (2006).

The TLC arrangement case study

The topology for the TLC arrangement is shown in Figure 2.

FIGURE 2. THE TOPOLOGY OF THE TLC ARRANGEMENT



The current NTCs among the TLC countries are shown in Table 3.

TABLE 3. CURRENT NTCS AMONG THE TLC COUNTRIES

NTC (forward/backward)	Summer 2007 (MW)	Winter 2006-2007 (MW)
Netherlands-Belgium	1900/2000	2400/2400
Belgium-France	1100/2700	1100/3200

The physical transmission capacity for the same interconnectors *differs* due to the definition of NTC which considers exchange program (see Appendix). Leuthold and Todem (2007) show that the difference between the calculated NTCs and flows can be substantial in a three-node network. For example, if one interconnector has auctioned NTC = 100 MW and the other has auctioned zero, the real flow will be 66.7 MW in the first interconnector and 33.3 MW in the others, although the auctioned NTC is zero. They also explain that a flow-based allocation method leads to higher BC values than NTC values for the same border and that the real flows are more representative in a flow-based auction.

Based on current price levels, an investment between France and the Netherlands appears most profitable. But since there are no direct cross-borders for these countries, an interconnector between France (F) and Belgium (B) appears reasonable based on the current price levels. We can analyze this using the model from Kristiansen and Rosellón (2006). The problem formulation is:

$$\begin{aligned}
&\underset{a,\hat{t},\delta}{Max}\; a(b_{FB}\delta_{FB}) \\
&\text{s.t.} \\
&T_{FB} + a\delta_{FB} \le C_{FB}^{+} \quad (\omega) \\
&T_{FB} + (\hat{t} + a)\delta_{FB} \le C_{FB}^{+} \quad (\gamma) \\
&\hat{t} \in \arg\max_{t} \{ t(p_{FB}\delta_{FB}) \} \\
&T_{FB} + \hat{t}\delta_{FB} \le C_{FB} \quad (\lambda) \\
&\delta_{FB}^{2} = 1 \quad (\varphi) \\
&a \ge 0 \quad (\kappa)
\end{aligned} \tag{10}$$

The Lagrange multipliers associated with each constraint are indicated within the brackets. The solution to this mathematical program can be found analytically as follows. The first constraint on simultaneous feasibility of incremental FTRs $T_{FB} + a\delta_{FB} \le C_{FB}^{+}$ is non-binding, because the grid is being expanded. The solution to this problem gives $\delta_{FB} = 1$, because the network is being expanded. Additionally $\gamma = b_{FB}$ implies that the higher the value of the investor-preference parameter b_{FB}, the more the investor values post-expansion transmission capacity (its marginal valuation of transmission capacity increases with the bid value). Similarly, we find $\lambda = p_{FB}$ which implies that the higher the value of the preset proxy preference parameter p_{FB}, the higher the marginal valuation of pre-expansion transmission capacity.[16]

We can also expect that $\varphi = 0$ because the expansion factor δ is non-zero. Furthermore, $\hat{t} = C_{FB} - T_{FB}$, meaning that for given existing rights, the higher the current capacity the larger the need for reserving some FTRs for possible negative externalities generated by the expansion. Finally, $a = C_{FB}^{+} - T_{FB} - \hat{t} = C_{FB}^{+} - C_{FB}$, which shows that the optimal amount of additional MWs of FTRs in direction δ depends directly on the amount of capacity

[16] We have omitted some calculations of Lagrange multipliers. These are $\theta = 0$, $\zeta = \gamma / p_{32} = b_{32} / p_{32}$ and ε = 0 (see Kristiansen and Rosellón, 2006). This was expected since only one restriction for the lower problem is binding because the other two are redundant. The value of the binding Lagrange multiplier equals the ratio between the investor's bid value and the preset proxy parameter.

expansion. Thus the investor receives incremental FTRs for the incremental capacity in which it has invested. If there are no existing FTRs, T_{FB} (the amount of proxy FTRs) equals the capacity of the interconnector before the expansion C_{FB} .

In cases where an interconnector is invested in parallel to the existing link the current model would give the same solution as in the case above. Both the proxy and incremental FTRs exhaust transmission capacity in the pre-expansion and expanded grid respectively. The proxy FTRs assist in allocating incremental FTRs by preserving capacity in the pre-expansion network, resulting in an allocation of incremental FTRs that equals he new transmission capacity created in the France-Belgium direction.[17] The proxy awards are transmission congestion hedges that can be auctioned to electricity market players in the expanded network.[18]

The auction problem becomes more complicated when any third interconnector is linked to the TLC arrangement (making it a triangular three-node network), such as investing in an undersea cable from France to the Netherlands without crossing Belgium. Moreover, the NorNed cable will come online in October 2007, linking the TLC countries with Nord Pool. This network topology will add another radial link to the TLC arrangement. The next possible expansion of the TLC might be a market coupling to Germany. Since Germany is expected to have an implicit auction with Denmark in the near future, the TLC market could be fully integrated with Nord Pool and Germany and thus facilitate a liquid and large geographical area.

Issues in FTR allocations

We now illustrate some of the challenges that arise from loop flows and merchant FTRs by using several examples from Kristiansen and Rosellón (2006) and Kristiansen (2006), but first we discuss the impact of PTDFs on allocation of FTRs.

Examples of projects that do not change PTDFs include appropriate maintenance and upgrades (*e.g.* low sag wires), and the capacity expansion of a radial line. Such investments could be rewarded with flowgate rights in the incremental capacity without affecting the existing FTR holders (we assume however that only FTRs are issued). In our three-node example, PTDFs change

[17] Note that this result will depend on the network interactions. In some cases the amount of incremental FTRs in the preference direction will differ from the new capacity created on a specific line. However, it will always amount to the new capacity created as defined by the scalar amount of incremental FTRs times the directional vector.

[18] When there are institutional restrictions to issuing LTFTRs, there will be an additional (expected congestion) constraint to the model. A proxy for the shadow price of such a constraint would be reflected by the preferences of the investor carrying out the expansion project (assuming risk neutrality and a price-taking behavior). The proxy award model takes the "linear" incremental and proxy FTR trajectories to the after-expansion equilibrium point in the ex-post FTR feasible set to ensure the minimum shadow value of the constraint.

substantially. In certain cases, these changes would not exist or would be minor if, for example, we insert a line in parallel with an existing line. In a large-scale meshed network, the change in PTDFs may not be as substantial as in a three-node network. However the auction problem is non-convex and nonlinear, and a global optimum might not be ensured. Only a local optimum might be found through methods such as sequential quadratic programming. In the following we describe two examples that illustrate the impacts of changing PTDFs (see the Appendix for how to calculate the PTDFs).

Transmission investment that does not change PTDFs

An example of an investment that does not change PTDFs is shown in figure 1 where there is an expansion of line 1-3 from 900 MW to 1000 MW transmission capacity. The associated feasible expansion FTR set is shown in Figure 4. We observe that any feasible FTRs that existed before expansion will become infeasible after the expansion.

FIGURE 1. THREE-NODE NETWORK WITH EXPANSION IN ONE LINE

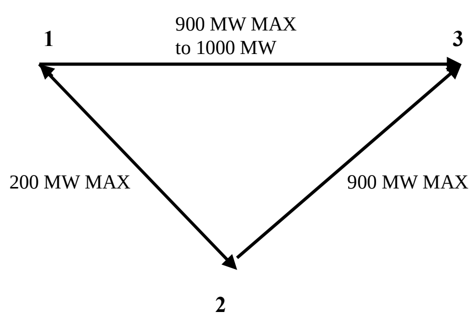
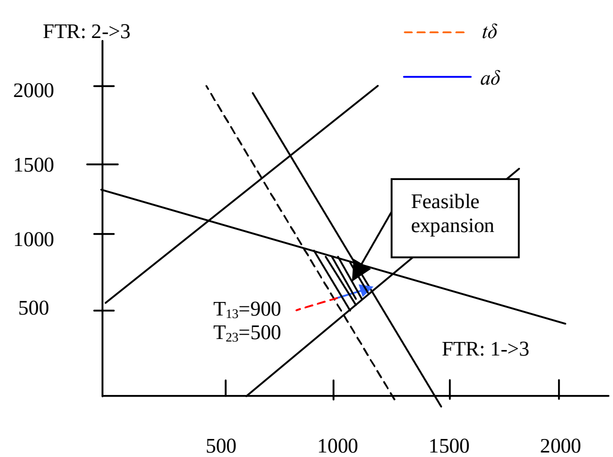


FIGURE 2. FEASIBLE EXPANSION FTR SET



Transmission investment that changes PTDFs

Figure 5 shows a three-node network that prior to expansion has 900 MW transmission capacity on line 2-3 while the expanded network has 1800 MW transmission capacity on the same line. Inserting a parallel line between nodes 2 and 3 with the same reactance as the existing line halves the total reactance between the nodes. For example, $PTDF_{12,13} = 1/3$ and $PTDF_{13,13} = 2/3$ will change to $PTDF_{12,13} = 0.4$ and $PTDF_{13,13} = 0.6$. Note that since the inserted line and the existing line have identical transmission capacity, the total transmission capacity doubles between buses 2 and 3. However, the simultaneous interaction of the reactances and transmission capacities changes the feasible expansion FTR set as illustrated in Figure 6 where we can see that some of the pre-existing FTRs may become infeasible. The physical characteristics of both networks are shown in Table 4 in the Appendix. The feasible region of expansion is shown in figure .

FIGURE 3. THREE-NODE NETWORK WITH EXPANSION OF ONE OF THE LINES

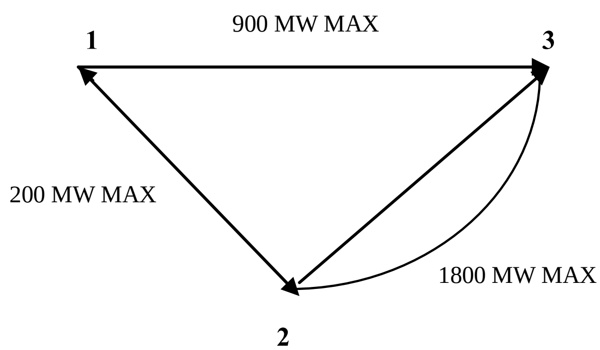


Figure 6 shows the feasible region of expansion (indicated by the cross-hatched area) in the pre-expansion network and the transmission constraints on the different lines. The feasible region of expansion is made possible by inserting another 2-3 line. Similarly, the reduction in the feasible pre-expansion region caused by the expansion is illustrated.

FIGURE 6. THE FEASIBLE REGION IN THE PRE-EXPANSION NETWORK

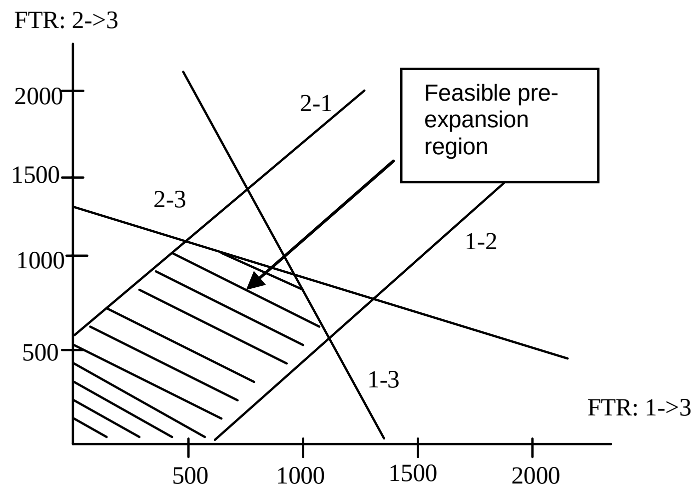
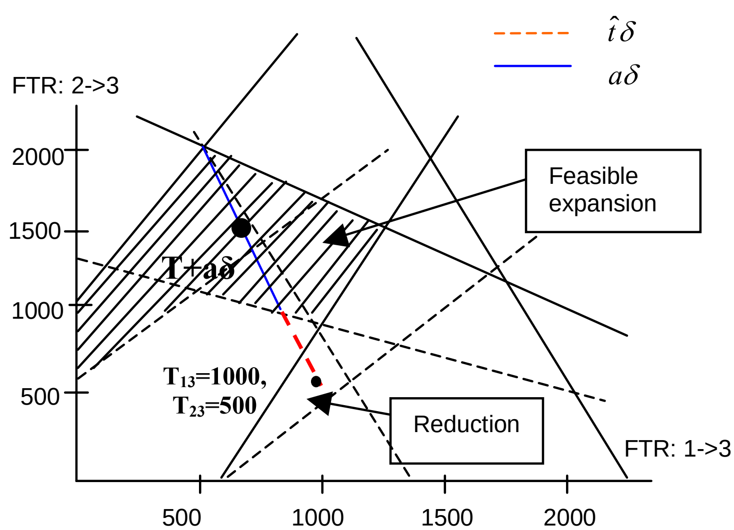


FIGURE 7. THREE-NODE NETWORK WITH EXPANSION OF ONE OF THE LINES



In the following we demonstrate how to find the solution shown in figure . We assume that lines 2-3 and 2-1 are fully allocated by FTRs (including proxies) after expansion and that line 2-3 is pre-expansion. The pre-existing FTRs do not use the full capacity of the pre-expansion network. The preference for FTRs after expansion is in the direction 2-3.

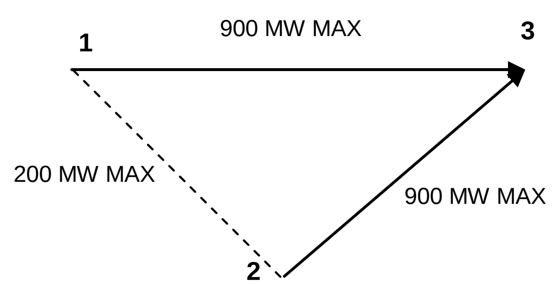
The MW amounts of awarded proxy FTRs in directions 1-3 and 2-3 are $\hat{t}\delta_{13} = -140$ and $\hat{t}\delta_{23} = 420$ and exhaust transmission capacity on the line 2-3. These proxy awards can be auctioned in the expanded network. The 1-3 proxy awards are mitigating FTRs and are necessary to restore feasibility. The MW amounts of awarded incremental FTRs are $a\delta_{13} = -360$ and $a\delta_{23} = 1080$. The solution, indicated by the large dot in figure , consists of both pre-existing and incremental FTR awards amounting to $T_{13} + a\delta_{13} = 640$ and $T_{23} + a\delta_{23} = 1580$.

The investor wants to maximize the sum of incremental FTRs. It is awarded 2-3 incremental FTRs amounting to the new transmission capacity it has created while simultaneously being responsible for more counterflows by buying back mitigating 1-3 incremental FTRs to restore feasibility. Thus the investor pays for the negative externalities it creates. The model tells us that transmission capacity is not exhausted in the expanded network because the pre-existing set of FTRs has become infeasible after the expansion and a minimal amount of mitigating 1-3 FTRs must be auctioned to restore feasibility.[19]

Other case studies

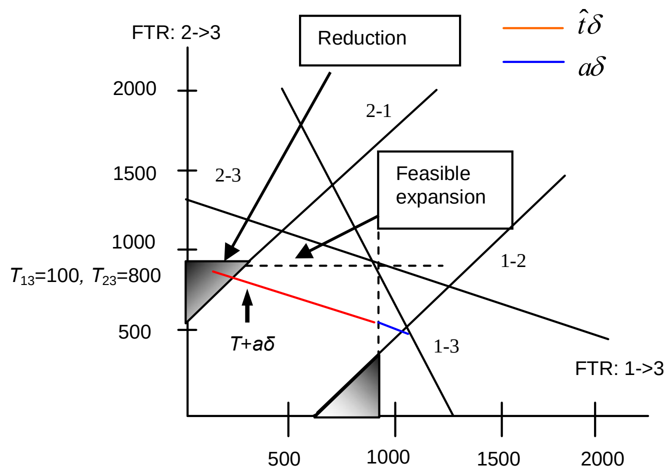
We first consider a three-node network example from Bushnell and Stoft (1997) where there is an expansion of line 1-2. The network is illustrated in Figure 8 and the feasible expansion region in Figure 9.

FIGURE 8. THREE-NODE NETWORK WITH EXPANSION OF LINE 1-2



[19] In principle, ordering effects when two successive projects are proposed should not matter, because the FTR auctions would be independent and the compensation the first investor receives from the second investor should equal the value of the FTRs (net of discount-rate issues).

FIGURE 9. FEASIBLE EXPANSION OF FTRS



In Figure 9, the pre-existing FTRs in the direction 2-3 do not use the full capacity of the pre-expansion network and become infeasible after inserting line 1-2. The preference is for FTRs in the direction 1-3 for transmission expansion. We note that the maximum amount of proxy and incremental FTRs in the direction 1-3 that can be obtained is 1100, corresponding to the point where the 1-3 and 1-2 transmission capacity constraints intersect.

We give the main results of the solution but for details regarding solution of the problem we refer to Kristiansen and Rosellón (2006). The MW amount of awarded proxy FTRs in the direction 1-3 is $\hat{t}\delta_{13} = 800$, and the amount of awarded incremental FTRs is $a\delta_{13} = 200$. The amount of incremental 1-3 FTRs corresponds to the new transmission capacity on line 1-2 that the investor has created. There is also an allocation of proxy FTRs such that the full capacity of line 1-3 is utilized. Similarly, the proxy awards in direction 2-3 are $\hat{t}\delta_{23} = -240$, and the amount of awarded incremental FTRs is $a\delta_{23} = -60$. The amount of incremental 2-3 FTRs is minimized (and they are mitigating FTRs that are necessary to restore feasibility). The investor is then responsible for additional counterflows and must pay for the negative externalities it creates. The solution (indicated by the black arrow in Figure 9) consists of both pre-existing and incremental FTR awards amounting to $T_{13} + a\delta_{13} = 300$ and $T_{23} + a\delta_{23} = 740$. The allocation of incremental 2-3 FTRs is minimized because the model accounts for the expansion of one line, and some of the pre-existing FTRs become infeasible after the expansion.

In the example provided by Bushnell and Stoft (1997), the investor with pre-existing FTRs chooses the most profitable incremental FTR based on optimizing its final benefit. The investor is then awarded a mitigating incremental 1-2 FTR with associated power flows corresponding to the difference between the ex-ante and ex-post optimal dispatches. The pre-existing FTRs correspond to the actual dispatch of the system and become infeasible after expanding line 1-2. Therefore, a mitigating 1-2 FTR[20] is allocated so that feasibility is exactly restored (that is, the investor "pays back" for the negative externalities to other agents). There is no allocation of proxy awards because the pre-expansion network is fully allocated by FTRs before the expansion. The amount of incremental FTRs is minimized because they represent a negative value to the investor and decrease its revenues from the pre-existing FTRs.

Welfare analysis

Bushnell and Stoft (1997) analyze the welfare implications of transmission expansion when dispatch matches both individually and in the aggregate. They show that under such conditions, social welfare is not reduced by an expansion of the transmission network.

Kristiansen and Rosellón (2006) assume unallocated FTRs both before and after the expansion, so that there is no match in dispatch. Their proxy award mechanism implies nonnegative effects on welfare of aggregate use for *FTR holders only,* since simultaneous feasibility and revenue adequacy are guaranteed before and after an expansion. However, since non-hedged agents in the spot market will be exposed to rent transfers, FTRs cannot provide perfect hedges ex post for all possible hedged and non-hedged transactions.

The merchant model used for the TLC arrangement in this paper should also meet these conditions. To validate this, we assume a social welfare function *B* for dispatch in a single period in the following welfare maximization:

$$\begin{aligned} &\underset{\Delta}{Max}\, B(Y^* + \Delta) \\ &\text{s.t.} \\ &K^+(Y^* + \Delta) \le 0 \end{aligned} \tag{11}$$

Where $Y^* \in \arg\max\{B(Y) | K(Y) \le 0\}$, Y^* is dispatch that maximizes social welfare without the expansion. Let Δ^+ be the dispatch that would be provided as an increment due to transmission expansion. Δ^+ solves this program.

If $P^+ = \nabla B(Y^* + \Delta^+)$, then under reasonable regularity conditions Δ^+ is a solution to:

[20] The incremental 1-2 FTR can be decomposed into a 1-3 FTR and a 3-2 FTR.

$$\begin{aligned} &\underset{\Delta}{Max}\, P^{+}\Delta \\ &\text{s.t.} \\ &K^{+}(Y^{*}+\Delta)\le 0 \end{aligned} \tag{12}$$

This is interpreted as the maximization of congestion rents for the incremental allocation Δ. If the current allocation of FTRs *T* satisfies $T = Y^{*}$, this program would provide the maximum value of incremental FTRs for expansion K^{+}, and this award would preserve the welfare maximizing property of the FTRs for the expanded grid.

Now suppose that $T \neq Y^{*}$. A “second best” rule might be:

$$\begin{aligned} &\underset{\Delta}{Max}\, P^{+}\Delta \\ &s.t. \\ &K^{+}(Y^{*}+\Delta)\le 0 \\ &K^{+}(T+\Delta)\le 0 \\ &Y^{*}\in \arg\max\{B(Y) \mid K(Y)\le 0\} \end{aligned} \tag{13}$$

Hence, the existing users of the grid could continue as before expansion, and the expander receives the incremental values resulting from the expansion. It can be shown that for certain expansion projects and topologies the only solution is $\Delta = 0$ so that the expansion project does not occur. We now test this argument for the expansion cases that we propose for the TLC coupling arrangement among the Netherlands, Belgium and France. For example, consider the case of expansion of the TLC arrangement with capacity between France and Belgium. The relevant constraints are:

$$\begin{aligned} T_{FB} + \Delta_{FB} \le C_{FB}^{+} \\ Y_{FB} + \Delta_{FB} \le C_{FB}^{+} \end{aligned} \tag{14}$$

Assume that $C_{FB} = 3500, C_{FB}^{+} = 4000, T_{FB} = 3000,$ and $Y_{FB} = 3500$. Thus there is a mismatch between the dispatch and existing FTRs of $Y_{FB} - T_{FB} = 500$. The marginal dispatch corresponds to $\Delta_{FB} = 500$. Substituting these numbers in the above constraints gives $Y_{FB} + \Delta_{FB} = 3500 + 500 = 4000$ and violates the constraints. Hence, the expansion occurs. Now let us interchange the dispatch and amount of existing FTRs to $Y_{FB} = 3000,$ and $T_{FB} = 3500$. The marginal dispatch corresponds to 1000 and violates the constraint $T_{FB} + \Delta_{FB} = 3500 + 1000 = 4500 > 4000$. Hence, the expansion does not occur.

Conclusion

In this paper we discussed the introduction of FTRs to the TLC border arrangement among the Netherlands, Belgium and France. The TLC has already proven to grant several benefits such as optimal use of cross-border transmission capacity, increased liquidity, and price stability and convergence. The mechanism is planned to be expanded through more interconnections between Germany and the Netherlands, Norway and the Netherlands, as well as the UK and the Netherlands. The potential introduction of FTRs to the TLC is part of a wider interest in Europe for hedging products for cross-border trade and congestion management by several regulatory bodies at the European continental level as well as at national levels (*e.g.*, Spain, France, and Italy). The efficient implementation of FTRs in meshed networks would require that TSOs handle flow-based transmission models that achieve simultaneous feasibility as well as revenue adequacy within an incentive regulatory framework.

In our paper, we simulated a model of optimal allocation of FTRs for an interconnector between France and Belgium when the ISO reserves some proxy FTR awards that resolve the negative externalities derived from transmission expansion. We showed the feasibility of such a project under our proposed FTR auction system, and corroborated several analytical results, such as the direct relationships between the post expansion capacity and the bid value of the investor's preference parameter, the current capacity and proxy FTRs, and the amount of capacity expansion and incremental FTRs.

We studied the likelihood of other projects, such as an interconnector that invests in parallel to an existing line, or a third interconnector that links to the TLC arrangement thus forming a three-node network (such as an undersea cable from France to the Netherlands, or the links with Nord Pool or Germany). We then looked at the potential to create loop flows both with and without changes in the PTDF structure. Although in many cases only local optima for an FTR auction might be achieved, our examples also demonstrated that FTR-supported expansion projects in Europe are technically and financially feasible. Our examples also confirmed the ambiguous welfare results implied by our FTR mechanism (Kristiansen and Rosellón, 2006), whenever some agents remain without hedging.

All of our analyses suggested that employing FTRs in TLC arrangements would require daily settlements in implicit auctions between power exchanges; clear definitions of the roles of TSOs and power exchanges (including training and procedural simplification); and the identification and provision of appropriate risk-sharing and regulatory incentives.

Appendix

Transmission capacity definitions (ETSO, 2001)

1. Total transfer capacity (TTC) is the maximum exchange program between two areas subject to security standards at each power system under perfect foresight of network conditions, generation and load patterns.
2. Transmission reliability margin (TRM) is a security margin that incorporates uncertainties about the calculated TTC values.
3. Net transfer capacity (NTC), defined as NTC= TTC – TRM, is the maximum exchange program between two areas compatible with security standards applicable in both and accounting for the technical uncertainties of the future network.
4. Already allocated capacity (AAC) is the total amount of allocated transmission rights including capacity or exchange programs.
5. Available transmission capacity (ATC), defined as ATC = NTC –AAC, is the portion of NTC that remains available after each phase of the allocation procedure for additional commercial activity.

Calculating PTDFs

PTDFs are an important parameter in our model. his example is for a lossless network defined by the following relationship between the net injection, the power flows P_{ij} and phase angles θ_i (Wood and Wollenberg, 1996):

$$P_i = \sum_j P_{ij} = \sum_j \frac{1}{x_{ij}}(\theta_i - \theta_j) \tag{15}$$

Where x_{ij} is the line inductive reactance in per unit and the net injection (or net generation) of power at each bus is denoted P_i. Inserting a line in parallel would lower the total reactance (for example assuming identical reactance halves the total reactance).

If we use the index 1 for APX, 2 for Belpex and 3 for Powernext we obtain:

$$\begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix} = \begin{bmatrix} \frac{1}{x_{12}} & -\frac{1}{x_{12}} & 0 \\ -\frac{1}{x_{21}} & (\frac{1}{x_{21}} + \frac{1}{x_{23}}) & -\frac{1}{x_{23}} \\ 0 & -\frac{1}{x_{32}} & \frac{1}{x_{32}} \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix} \tag{16}$$

The matrix (called the susceptance matrix) is singular, but by declaring that one of the buses (bus 1) has a phase angle of zero and eliminating its row and column from the matrix, the reactance matrix can be obtained by inversion. In the case of identical reactance with unity we have:

$$\begin{bmatrix} P_2 \\ P_3 \end{bmatrix} = \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} \theta_2 \\ \theta_3 \end{bmatrix} \tag{17}$$

The resulting equation then gives the bus angles as a function of the bus injection:

$$\begin{bmatrix} \theta_2 \\ \theta_3 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} P_2 \\ P_3 \end{bmatrix} \tag{18}$$

The *PTDF* is the fraction of the amount of a transaction from one bus to another that flows over a given line. $PTDF_{ij,mn}$ is the fraction of a transaction from bus *m* to bus *n* that flows over a transmission line connecting bus *i* and bus *j*. The equation for the *PTDF* is:

$$PTDF_{ij,mn} = \frac{x_{im} - x_{jm} - x_{in} + x_{jn}}{x_{ij}} \tag{19}$$

Where x_{ij} is the reactance of the transmission line connecting bus *i* and bus *j* and x_{im} is the entry in the i^{th} row and the m^{th} column of the bus reactance matrix. In total we find the following $PTDFs$:

$$\begin{aligned} &PTDF_{12,12} = 1,\ PTDF_{12,21} = -1,\ PTDF_{12,13} = 1, \\ &PTDF_{12,31} = -1,\ PTDF_{23,23} = 1,\ PTDF_{23,32} = -1,\ PTDF_{23,21} = 1 \\ &PTDF_{23,12} = -1 \end{aligned} \tag{20}$$

In practice, the reactances are not identical. Studying the current NTCs and flows will help us determine some of the differences between the current physical model and the commercial model. The analytical solution for the case is:

$$\begin{bmatrix} \theta_2 \\ \vartheta_3 \end{bmatrix} = \frac{1}{\frac{1}{x_{32}}\left((\frac{1}{x_{21}} + \frac{1}{x_{23}}) - \frac{1}{x_{32}} \right)} \begin{bmatrix} \frac{1}{x_{32}} & \frac{1}{x_{23}} \\ \frac{1}{x_{32}} & (\frac{1}{x_{21}} + \frac{1}{x_{23}}) \end{bmatrix} \begin{bmatrix} P_2 \\ P_3 \end{bmatrix} \tag{21}$$

TABLE 4. PHYSICAL CHARACTERISTICS OF THE PRE- AND POST EXPANSION NETWORKS FOR THE NETWORK IN FIGURE 5

Pre-expansion network				
	Transmission capacity (MW) / reactance (per unit)		**Power transfer distribution factors (PTDFs)**	
Line 1-3	900	1	$PTDF_{13,13}=2/3$	$PTDF_{13,23}=1/3$
Line 2-3	900	1	$PTDF_{23,13}=1/3$	$PTDF_{23,23}=2/3$
Line 1-2	200	1	$PTDF_{12,13}=1/3$	$PTDF_{12,23}=-1/3$
Line 2-1	200	1	$PTDF_{21,13}=-1/3$	$PTDF_{21,23}=1/3$
Post-expansion network				
Line 1-3	900	1	$PTDF_{13,13}=0.6$	$PTDF_{13,23}=0.2$
Line 2-3	1800	1/2	$PTDF_{23,13}=0.4$	$PTDF_{23,23}=0.8$
Line 1-2	200	1	$PTDF_{12,13}=0.4$	$PTDF_{12,23}=-0.2$
Line 2-1	200	1	$PTDF_{21,13}=-0.4$	$PTDF_{21,23}=0.2$

References

APX (2007), homepage: www.apxgroup.com

Brunekreeft, G. Regulatory issues in merchant transmission investment, Utilities Policy.

Bushnell, J. B. and S. E. Stoft (1996). Electric Grid Investment Under a Contract Network Regime, *Journal of Regulatory Economics* 10, 61-79.

__________(1997). Improving Private Incentives for Electric Grid Investment. *Resource and Energy Economics* 19, 85-108. ETSO (2007), Regional Flow-based allocations–State of play, final paper, March.

ETSO (2006), Transmission Risk Hedging Products. Solutions for the Market and Consequences for the TSOs, Background Paper, February.

Hogan, W. (1992). Contract Networks for Electric Power Transmission. *Journal of Regulatory Economics*, 4, 211-242.

__________(2000). Flowgate rights and wrongs, handout, JFK School of Government, Harvard Electricity Policy Group, Harvard University, http://www.ksg.harvard.edu/people/whogan.

__________(2002b). Financial Transmission Right Formulations. Handout, JFK School of Government, Harvard Electricity Policy Group, Harvard University: http://www.ksg.harvard.edu/people/whogan

__________(2002a). Financial Transmission Right Incentives: Applications Beyond Hedging. Presentation to HEPG Twenty-Eighth Plenary Session, May 31, http://www.ksg.harvard.edu/people/whogan.

Kristiansen T. and J. Rosellón (2006). A Merchant Mechanism for Electricity Transmission Expansion, *Journal of Regulatory Economics,* Volume 29, Number 2, pp. 167-194, March.

Kristiansen T. (2007). Allocation of long-term financial transmission rights for transmission expansion, *European Journal of Operational Research,* forthcoming.

Leuthold F. and C. Todem, Flow-Based Coordinated Explicit Auctions: Auction Income Distribution, working paper 2007.

O'Neill, R.P., U. Helman, B.F. Hobbs, W.R. Stewart and M.H. Rothkopf (2002). A Joint Energy and Transmission Rights Auction: Proposal and Properties, IEEE Trans. Power Systems, 17(4), November, 1058-1067.

Philpott, A. and G. Pritchard (2004). Financial transmission rights in convex pool markets, Operations Research Letters, Volume 32, Issue 2, March, 109-1.

RTE, ELIA and Tennet (2006), Management of interconnection capacities, presentation, January.

Wood, A. J. and B. F. Wollenberg (1996). Power Generation, Operation and Control, John Wiley & Sons, New York.

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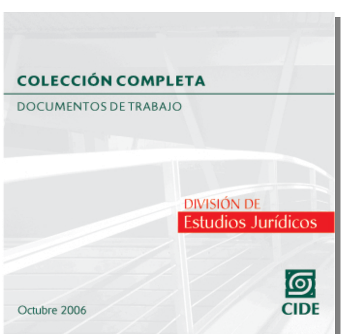

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