Design of a Transmission Rights Exchange

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Introduction

It has long been recognized that the loop flow effects of power on an interconnected network may pose special problems for the design of efficient trading mechanisms for electricity (Hogan 1992). One mechanism currently used for the design of a power market is based on the electricity spot pricing literature (Schweppe *et al.*, 1988). These locational marginal pricing (LMP) systems depend on centralized optimization of supply and demand bids to reach a productively efficient solution, and to provide a price at many or all nodes on the network.[1] Transmission trading under this market structure is generally based on financial hedging contracts (Hogan 1992). However, this method is not without its drawbacks. It requires a substantial amount of centralized decision-making, which may be institutionally difficult or unacceptable, especially in regions that have not previously operated as a single control area. The system operator needs complete information on the supply and demand functions of all market participants, and must rely on complex optimization algorithms to derive prices. Information and transaction costs for the central operator are likely to be high.

More recently, flow-based systems have attracted increased attention as a potentially efficient method of trading, and one that does not require centralized optimization (Chao, Peck, Oren and Wilson 2000 and Tabors Caramanis and Associates, 2000). This market form is based upon the economic analysis of Chao and Peck (Chao and Peck 1996). Under a flow-based mechanism, the system operator will initially define and allocate a limited number of physical transmission rights to market participants that reflect the maximum allowable power flows across lines, elements or transmission interfaces. Participants must acquire a portfolio of flow-based or flowgate rights to complete their point-to-point trade.[2] The portfolio of flow-based or flowgate

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[1] The LMP framework under the usual assumptions should provide a *productively efficient* solution, even where the set of FTR markets is incomplete. However, absent a full set of state-contingent FTR markets the equilibrium will remain Pareto inefficient (Adamson 2000).

[2] Trading in the Chao-Peck / flow-based framework may be from each node to other nodes in the network or to and from a defined “hub” node. A flowgate right may be defined across a single network element (e.g. a transmission line) or across a broader transmission interface, and thus represent a set of individual network elements.

rights required to make a trade from one point or node to any other is calculated from the power transfer distribution function (PTDF) or trading matrix. The trading in these Coasian flow-based transmission rights should produce a productively efficient outcome if all gains from trade are realized.

One complicating feature of flow-based trading on an electricity network is the potential for counterflows on certain elements. For example, a trade from one point on a power network to another may actually relieve congestion, by producing flows in the opposite direction. This may be represented in the flow-based or Chao-Peck framework as the creation of new flow-based or flowgate rights, where the impact of a trade on a potentially constrained flowgate is negative. Trades scheduled on the network must be treated as obligations, not options, to ensure that the final flows can be accommodated on the network where counterflows are produced (Ruff 2000b).

The flow-based method of trading, while it does not require the degree of centralization in the system operator function that is required in the LMP method, also suffers from potential drawbacks. The number of transmission rights that must be defined to account for all of the actual or possible (e.g. state-contingent) constraints on an actual network may be large and impractical (Hogan 2000). Transaction and information costs for traders may be high, especially if the physical realities of the network in question require that many rights must be traded in order to reflect the actual constraints on power flows. Markets for rights may be illiquid or thinly traded, and it therefore may be difficult for the market mechanism to converge to an efficient result. Given the large number of individual flow-based trades that might be required, it may also be difficult for individual traders to make informed decisions about their production, consumption and marketing positions. Another mechanism may be required in order to make Chao-Peck pricing efficient and practical given real-world limitations on information flows, etc. (Stoft 1998). This paper presents one possible solution.

Trading in point-to-point transmission congestion rights

As noted by Chao, Peck Oren and Wilson in a recent paper, flow-based rights are in a sense more fundamental that point-to-point rights (Chao, Peck, Oren and Wilson, 2000). After all, it is the ability to transfer power across individual lines or network elements that is truly scarce. However, such flow-based rights are not the final product of interest to generators, loads, and traders in a market. Their commercial interests instead focus on the point-to-point rights necessary to conduct actual trades in the market.

Trading in point-to-point transmission rights – which may themselves be thought of as bundles of individual flow-based or Chao-Peck rights – may be efficiently conducted through an exchange or other market mechanism if this trading is not done on a one-to-one quantity basis. Under this method of trading rights (either point-to-point rights or bundles of flow-based or flowgate rights) is based on the ratio of the PTDF matrix elements (for the point-to-point rights) for the binding constraints.[3] Traders may buy and sell point-to-point transmission rights (or

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[3] Where multiple transmission constraints are binding, the most restrictive ratio would be used. For example, assume that two constraints are binding, and that an increase in output of 100 MW by Gen A would require

other bundles of individual flow-based or flowgate rights) through the exchange, instead of assembling the portfolio of rights through individual transactions. This should facilitate the development of energy and transmission markets with greater liquidity, better price discovery and lower transaction costs.

Example of transmission congestion trading

Figure 1 shows a simple example of an electric network, with two generators located at nodes A and B, and the electrical load at node C. Maximum power flows on each line are shown next to the arrows. Even on this simple system, trading of three or more transmissions rights may be required in separate markets in order to reach a technically feasible and productively efficient solution.

Figure 1: Example 1 - Three node system

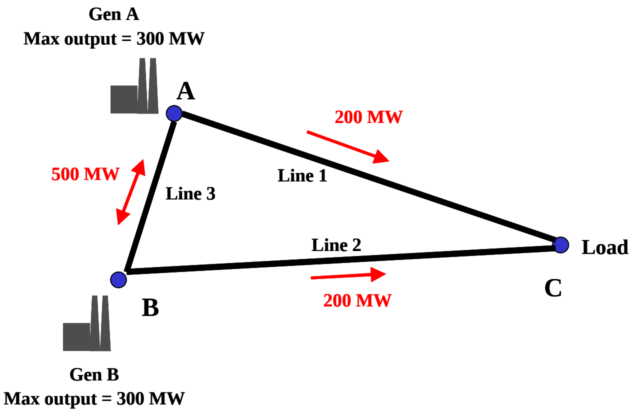

Table 1 shows some elements of the PTDF or trading matrix for this simple example. Two possible trades are shown by the headings across the top (from A to C and from B to C), while the impacts on individual lines or flowgates are shown in the columns. For example, a 100 MW transfer of power from node A (Gen A) to node C (Load) would require the trader to acquire 66.67 MW of line 1 (flowgate 1) rights, and 33.33 MW of line 2 and line 3 (flowgate 2 and 3) rights. It is easy to see that this trading process might be cumbersome and impractical if dozens or hundreds of rights must be traded to reflect the physical operations of a complex power or other network.

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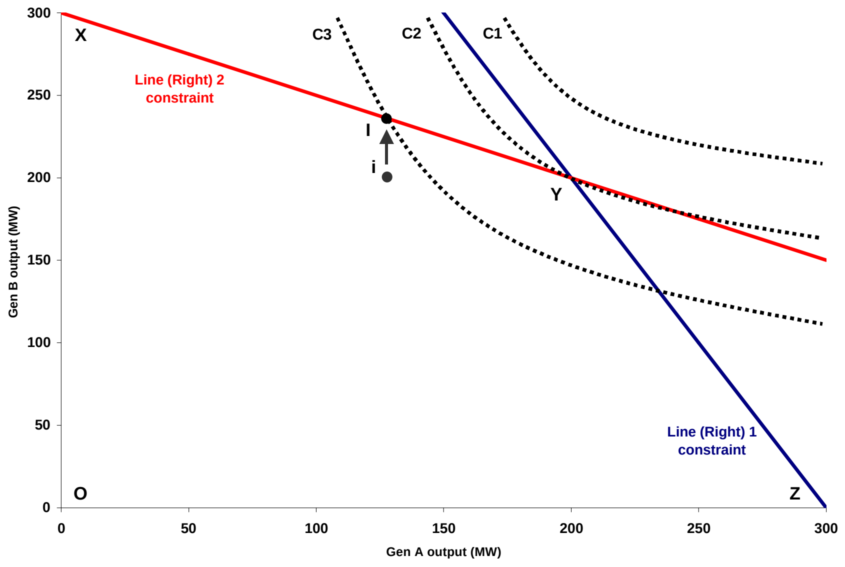
that Gen B decrease its output by 50 MW to keep one transmission constraint from being breached, but that Gen B would only need to drop by 10 MW to keep the second constraint from being breached. Trades between point-to-point transmission rights A to C and B to C would be at the 2:1 ratio, not the 10:1 ratio. The PTDF matrix may also be referred to in various applications as the trading matrix or function, impact matrix, or admittance function.

Table 1: Power Transfer Distribution Matrix (partial)

	A-C	B-C
Line 1 (A-C)	0.6667	0.3333
Line 2 (B-C)	0.3333	0.6667
Line 3 (A-B)	0.3333	-0.3333

The combination of a (linear) power transfer distribution function – e.g. the fixed element matrix in Table 1 – combined with fixed line or flowgate limits produces (linear) constraints in the space defined by the output of Gen A and Gen B. These constraints are illustrated by the thick lines in Figure 2. The line XY is determined by the maximum flow on Line 2, the lower transmission line in Figure 1. The line ZY is determined by the maximum flow on Line 1 – e.g. the output of Gen A times the corresponding PTDF element (0.6667, as shown in first column of Table 1) plus the output of Gen B times its corresponding PTDF element (0.3333) must be no greater than 200 MW. Three isocost curves (curves of constant production costs for an equivalent level of output) are also shown in Figure 2, where the cost of C3>C2>C1. Points on the isocost curves farther from the origin therefore represent a lower total cost.[4]

Figure 2: Transmission constraints and trade equilibrium in Example 1



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[4] Not shown on the graph is the total quantity constraint, for presentational purposes. Interpreting the isocost curves as representing total costs, including the expected costs of unserved energy, allows the normal interpretation of the figure to be maintained.

Assume that the initial allocation of rights, for the purpose of this example, is technically feasible, and would give Gen A and B outputs as shown at ***Point i*** in Figure 2. At this point no transmission constraint is binding, so traders can submit additional transactions to the system operator or exchange without creating any additional constraints. At some point transmission constraints do become binding, as represented by the move to ***Point I*** on the diagram.

If the cost function is well behaved, then any efficient solution lies on the frontier defined by the space ***OXYZ***. Any cost-minimizing (welfare maximizing) trade will therefore involve tradeoffs between the output of Gen A and Gen B. However, as the slope of line ***XY*** illustrates, such tradeoffs are not made on a one-to-one basis. The slope (or inverse slope, depending n the convention) of line ***XY*** is instead determined by the ratio of the power transfer distribution function elements *for the constraint that is binding*. In this case, this is the Line 2 constraint. The ratio of power transfer distribution elements is therefore 0.6666 / 0.3333 = 2. In other words, if Gen A is to increase its output by 100 MW, then Gen B must drop its output by 50 MW, as its proportional impact on the constrained line is twice as high.

This trading will be mutually beneficial – following the constraint line ***XY***, until point ***Y*** is reached. This is the lowest cost isocost curve intersected by the frontier ***OXYZ*** and is the trading equilibrium. At this point further trading between Gen A and Gen B output would be at a new exchange rate, defined by the inverse slope of line ***YZ***, based on the ratio of PTDF elements where the Line 1 constraint was binding.

A practical network may contain dozens, hundreds or even thousands of actual or possible constraints, not just the two constraints illustrated above. However, trading could still work on the same basis, although the frontier of possible inputs and outputs, instead of forming the simple polygon shown in Figure 2 (***OXYZ***), will instead take the form of a multidimensional surface.

Transmission exchanges and market structures

One significant potential advantage of this approach is its flexibility – the basic functional concept of the transmission market or exchange could be accommodated within a wide framework of power market structures. The transmission market could be independent, or integrated with, the system operator function that actually operates the transmission system. Trading in transmission rights could be conducted by an exchange that matched buyers or sellers, or market makers in transmission rights could develop who would take short-term positions in the market, swapping capacity back and forth between other participants using the trading mechanism described above. In theory, there could even be multiple competing transmission rights markets, where participants could acquire the rights necessary to schedule transactions with the system operator.

In the interests of simplicity, the remainder of this section describes the operation of a transmission rights exchange that matches buy and sell offers for transmission rights on the basis of the rules described previously. The transmission rights exchange could be institutionally integrated with, or independent of the system operator, although some communication between the two is necessary as the exchange must know what constraints are binding at each time – given the transmission schedules previously submitted - so that efficient trades between point-to-point rights can be made.

In this example, it is assumed that there is an energy market operating at a specified "hub", where blocks of energy can be bought and sold on a continuous basis. It is also assumed that through some process – exogenous to the operation of the market – that an allocation of some point-to-point transmission rights has been made to participants. This could be done through an auction, or some other means.

The broader (day-ahead or some other longer or shorter period) power market would operate in the following fashion:

1. Participants would have an initial set of point-to-point transmission rights. These might be from the location of a generator to a central hub, from the hub to the locations of loads, or any other allocation.
2. The system operator would determine, on the basis of the information available, the PTDF matrix and flow constraints for the period. This might need to be updated as transmission conditions change.
3. The system operator, functioning in a *de minimis* role in this example, would accept transmission schedules accompanied by the appropriate quantities of point-to-point rights. Upon acceptance of a schedule, the system operator would notify the participant and the expected flows (based on the PTDF matrix) would be included in the SO's database. Acceptance of a transmission schedule creates an obligation for power to flow where a counterflow is created. The counterflow rights created by such a transaction can be used by the participant or sold to others.
4. Once a schedule had been accepted, the system operator would update its database of scheduled flows, and notify the exchange operator and participants of current binding transmission constraints.
5. A transmission schedule not backed with the appropriate point-to-point rights would be conditionally accepted by the system operator if the flows to be created would not reach the constrained level on any line, given the schedules already accepted and the set of outstanding transmission rights that have not been used.[5] This rule ensures that the transmission capabilities of the network are always used up to the efficient level. If a constraint were binding (or would be binding) as a result of the proposed schedule then the schedule would be rejected.

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[5] At a pre-defined time holding a transmission right may create the obligation, rather than just an option, to transmit power, in order to deal with counterflows. A participant not wanting to schedule could sell its rights to another trader or release them back to the system operator. After this time the initial holder of the rights would lose any priority in scheduling. This obligatory aspect - after a certain period - helps addresses the market power issues raised by Stoft (Stoft 1998), and is similar to the release rules proposed by other authors.

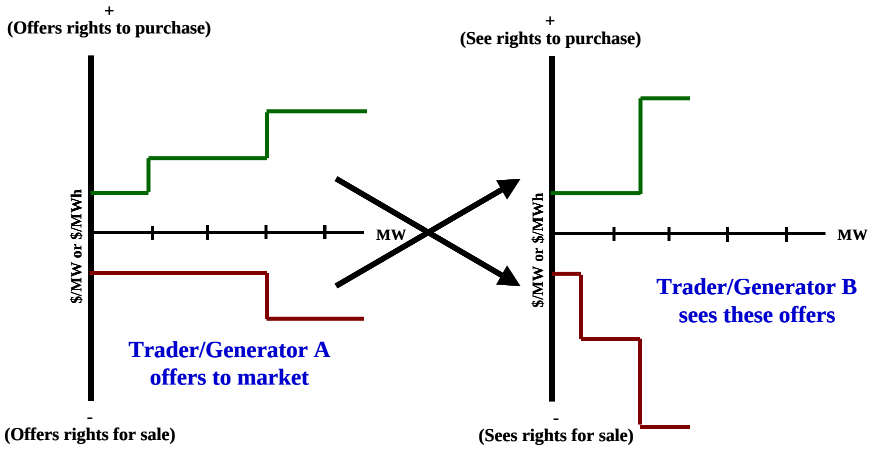
6. A participant wishing to make a transaction, and not holding the appropriate quantity of transmission rights, could acquire additional rights or sell those already held which had not been used to back previous transactions. This is described in further detail below.
7. Once the participant had acquired the appropriate quantity of point-to-point transmission rights then the transaction could be re-submitted to the system operator, where it would now be accepted.

Design of a transmission rights exchange

Under this design, offers to buy and sell "local" point-to-point rights would be made, and could be converted by the exchange operator into equivalent buy and sell offers at other locations, based on a quantity "exchange rate". This exchange rate, as noted previously, would be calculated for different participant pairs based on their locations (and hence their different PTDF matrix elements) for the currently binding constraints. The effect of the exchange could thus be to "translate" one quantity of rights into another, as is shown in Figure 3.

This figure shows the exchange rate calculation at a specific point (***Point I***) in Example 1. On the left hand side of Figure 3, Trader / Generator A could offer to buy and sell rights (in this case, point-to-point rights from Node A to Hub (Load) node C. These could be shown as the price-quantity blocks above and below the horizontal axis. Offers to purchase new rights are shown in this sign convention as being at positive $ / MW price, while offers to sell rights are illustrated at a negative price. In the new invention, the exchange could then convert these offers to equivalent Node B to C rights when the offers are made to Trader / Generator B. Following the previous example; it was shown that the quantity exchange rate at this point (***Point I***) was 2:1. Thus the quantities could be adjusted when they are presented to Trader B. For example, an offer to buy 100 MW of rights by Trader A could become an offer to sell 50 MW of rights by Trader B. Conversely, an offer by Trader A to sell 50 MW of transmission rights might be converted to the offer for Trader B to purchase only 25 MW of additional transmission.

Figure 3: Rights offers from Trader A to Trader B in exchange (at Point I - Line 2 constraint binding)



Note: This illustration is not to scale

The transmission rights market might operate as a continuous double auction (CDA) mechanism, or under other auction structures. These mechanisms are widely discussed in the auction theory literature. Ordinary trading in flow-based rights could be conducted independently of the exchange mechanism, if this was desired. The objective of the transmission rights exchange or market is to create a low transactions cost mechanism for acquiring the needed point-to-point rights.

Improving information flows to market participants

One stumbling block to the successful implementation of flow-based market models on complex networks is the potential for higher information and transactions costs for users. The key question for any single user of the transmission system is relatively simple – what is the cost or benefit associated with an additional transaction? For a load, this question becomes what is the cost of consuming another MW of energy – incorporating both the costs of energy and the transmission necessary to deliver it – or the benefit of reducing consumption. For a generator, this question may be rephrased as what is the expected benefit of selling another MW of energy in the period, accounting for the costs of transmission necessary to deliver it to the hub.[6]

The transmission rights exchange model allows these “netback” prices to be calculated easily, and updated continuously. For example, assume that the hub energy and transmission rights

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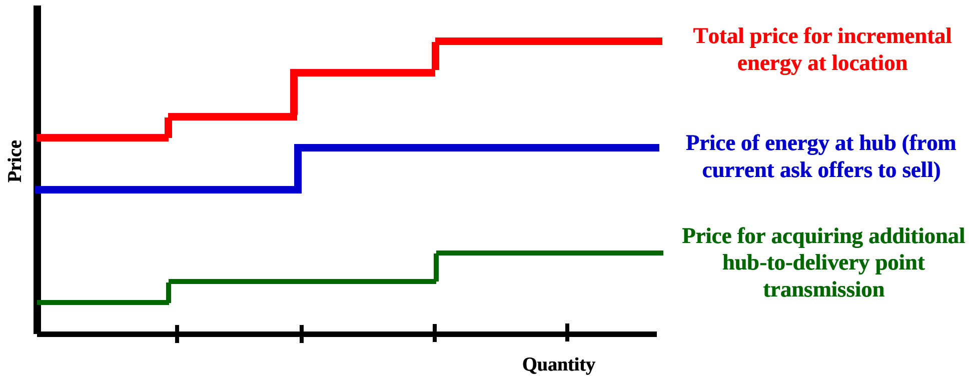
[6] It should be remember that this transmission cost may be negative, where counterflows are produced whose value exceeds the cost of other rights that must be acquired.

markets operate as a continuous double auction, with a set of uncleared bid and ask prices for blocks of energy or transmission capacity available on a continuous or near-continuous basis. The incremental cost of consumption at any node can then be easily calculated, as shown in Figure 4, by combining the outstanding offers to sell energy at the hub with the costs of acquiring additional hub-to-delivery point transmission rights on a piecewise basis. This calculation could be easily conducted by the individual user, or by the operator based on the market data current at the time.

Figure 4: Incremental costs for additional consumption at load node



By reversing the calculation, the user can also easily calculate the economic benefit from reducing consumption. This could be done by taking the current bids to buy energy at the hub, combined with the value of selling transmission (based on the current bids to buy transmission, converted for the load's location) from the transmission rights market. An analogous set of "netback" calculations could be done for generators. The effective demand schedule for a generator could be calculated from the outstanding bids to buy energy at the hub, minus the costs of acquiring additional generator-to-hub transmission capacity.

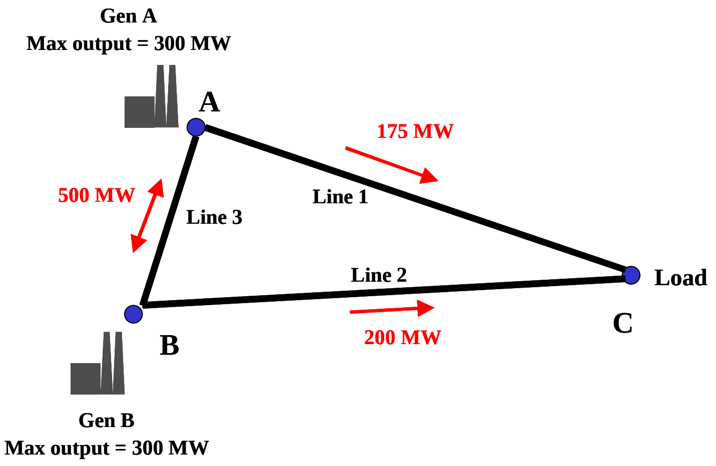
The net effect of this structure is to create price signals for both generators and loads that reflect not only the costs of producing energy at the hub but also the indirect costs of transmission constraints. In this respect the prices created are similar to those produced in the LMP model. There are, however, some important differences. The continuous prices transmitted to loads and generators, instead of being only advisory, are binding, and are based on actual commitments to buy and sell energy and transmission. There would appear to be considerable economic benefits in particular from allowing loads to see binding prices in the market while there is time to react, rather than waiting until after the fact.

Incorporating new transmission constraints

In defining flow-based rights, it may be difficult and contentious to define a complete set of flow-based or flowgate rights in advance that adequately captures the actual constraints on the system, given the contingencies that may occur (Hogan 2000 and Ruff 2000a and 2000b). For example, flowgate rights might be defined well in advance, but on the day of operation changes in transmission constraints (due to changes in network status and line outages, for example) might require that new constraints be added or that existing constraints be changed in order to reflect the actual state of the transmission system. If these flowgates have not been previously defined, then the trading equilibrium might produce a commitment schedule that is not technically feasible – e.g. it might produce transmission flows that would breach the new constraint(s). A new flowgate might be defined, and the transmission rights then auctioned or otherwise allocated, but this may be cumbersome and costly. As the operating hour approaches there could be less and less time available to conduct such changes to the number and quantities of flowgate rights.

Under the proposed transmission rights exchange model, this issue should pose a substantially smaller problem. If the initial allocation of rights is still technically feasible (after considering the new constraint), than an efficient solution cay still be found, with no costly or time-consuming process needed for allocating and trading "new" flowgate rights. This is illustrated in Figure 5. In this example, a change in the transmission system requires that flows on line 1 be constrained to 175 MW, and not 200 MW as in the previous example.

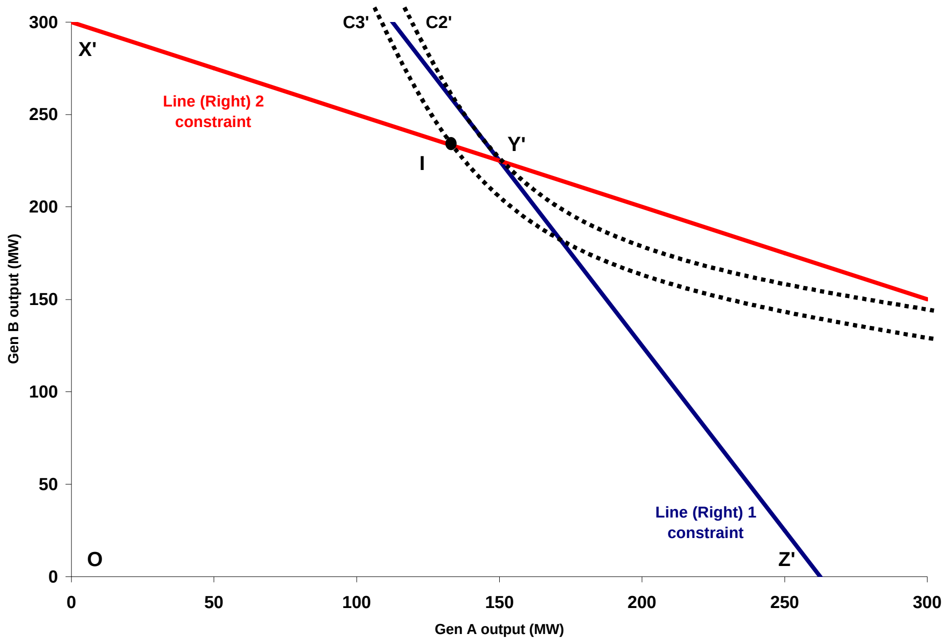
Figure 5: Example 2 – Three node system with a change in constraints



This produces a change in the line 1 constraint (line ***Y'Z'***) in Figure 6. Assume that the starting allocation is at ***Point I***. Initial trading between Trader A's rights (A to C) and Trader B's rights (B to C) could continue to be on a 2:1 quantity basis, reflecting the fact that the line 2 constraint remains binding. However, the new trading equilibrium is not at ***Y'***, not at the original ***Y***, reflecting that the line 1 constraint has moved in towards the origin. The trading equilibrium is therefore touches a new isocost curve ***C2'***, which represents a higher cost than the original equilibrium.

This aspect of the invention represents a significant practical advantage over existing flow-based methods for transmission congestion trading. New rights would not necessarily have to be created as transmission constraints change, as long as the initial allocation was feasible.[7]

Figure 6: Transmission constraints and trade equilibrium in example 2



Conclusions

A new method of trading point-to-point transmission rights has been presented, based on the principles of unequal exchange rates between different point-to-point transmission rights. This trading approach may some improvements over the existing methods of trading in energy and transmission rights in some circumstances:

- This model does not require the substantial degree of centralization required in the LMP model, and the central operator will require substantially less information about the supply and demand preferences of individual traders.

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[7] If the existing rights allocation was not feasible, with the changes in constraints or PTDF matrix caused by unexpected contingencies, various rights allocations methods might be used. All rights could be scaled downwards until the constraint set could be met, or only those traders who had not paid for priority could be see their rights reduced. Under any of these circumstances, once a feasible starting rights position has been created the operation of the transmission exchange or market should lead to an efficient result.

System operator software could be substantially simpler, and the decisions of system operators less contentious. No complex optimization is required – only multiplication and division.

- Traders and other market participants are not required to trade in many individual flow-based rights in order to complete a single transaction, with the possibility for significant informational and transaction costs, and for poor price convergence and discovery if these costs were to prove high. Traders, instead of undertaking to buy and sell numerous rights to conduct one simple transaction, could relatively easily buy the additional rights needed to sell or buy another block or energy and to transmit it to or from the delivery point.
- New constraints may be easily accommodated in this trading mechanism, without the costs and delays of auctioning or issuing new flow-based rights, etc. This is described in more detail in the next section.
- Information flows to individual system users may also be improved, allowing buyers and sellers to easily calculate the total costs and benefits of additional transactions in the market. This too should help to lower costs and increase economic efficiency.

Designing efficient and effective power markets has not proved an easy task, due to the complex interactions between transactions on an AC network. While the flow-based systems proposed by Chao, Peck Oren and Wilson, among others, hold considerable promise for the development of market mechanisms that efficiently reflect the loop flow externalities inherent in electric power, the number of rights needed may limit the effectiveness of this approach in large networks with many potentially binding constraints.

The development of a transmission rights exchange or market may improve the performance of flow-based market designs, and provide better price discovery and price signals to participants. Given the recent problems that have arisen in U.S. power markets, the prospect for better and binding price signals being sent to loads - in time for them to respond - would in itself be a substantial improvement over current practice in most jurisdictions.

References

Adamson, Seabron (2000) “Flow-based versus Locational Marginal Pricing of Transmission Congestion: Contingencies and Efficiency”, unpublished draft mimeo, October 24th, 2000.

Chao, Hung-Po and Stephen Peck (1996) “A Market Mechanism for Electric Power Transmission” *Journal of Regulatory Economics*, **10**, 25-59.

Chao, Hung-Po, Stephen Peck, Shmuel Oren and Robert Wilson (2000) “Flow-based Transmission Rights and Congestion Management”, *Electricity Journal*, Vol. 13, No. 8 (October 2000), 38-58.

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

Hogan, William (2000) “Flowgate Rights and Wrongs”, unpublished mimeo, August 20th, 2000.

Ruff, Larry E. (2000a) “Flow-Based Transmission Rights and Congestion Management: A Comment” unpublished mimeo, August 17th, 2000.

Ruff, Larry E. (2000b) “Flowgates vs. FTRs, and Options vs. Obligations” unpublished mimeo, August 26th, 2000.

Schweppe, Fred C., Michael C. Caramanis, Richard D. Tabors and Roger E. Bohn (1988) *Spot Pricing of Electricity*, Norwell, MA: Kluwer Academic.

Stoft, Stephen (1998) “Congestion Pricing with Fewer Prices Than Zones” *The Electricity Journal*, May 1998, 23-31.

Tabors Caramanis and Associates (2000) “Real Flow: A Preliminary Proposal for a Flow-based Congestion Management System”, Cambridge, MA, July 18th, 2000.