A CONCURRENT AUCTION MODEL FOR TRANSMISSION CONGESTION CONTRACTS

WILLIAM W. HOGAN

Center for Business and Government
John F. Kennedy School of Government
Harvard University
Cambridge, Massachusetts 02138

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William W. Hogan[1]
Harvard University
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Introduction

Network interactions in the electricity system create externalities that have precluded the development of a workable system of fully decentralized "physical" property rights for controlling use of the transmission system in an open access, competitive electricity market.[2] Transmission congestion contracts provide a well-defined alternative mechanism to serve in the place of strictly physical property rights related to transmission usage. Any of a number of methods could provide an initial allocation of transmission congestion contracts. For instance, existing users might receive a designated set of contracts based on historical usage patterns, and then the remainder could be assigned to new users. With the availability of well defined transmission congestion contracts, it would be natural to employ an auction for allocating part or all of the contracts to allow for non-discriminatory access through a market mechanism.

The details of an auction could accommodate many special features of the transmission system. The essence in the context of a contract network framework is to ensure that the allocated contracts are feasible given the configuration of the network. In this case, a straightforward adaptation of an optimal power flow dispatch model provides a formulation of a concurrent auction model for selecting the long-term capacity awards based on the willingness to pay. The power flow formulation of the auction avoids the necessity of identifying which transmission congestion contracts are available by characterizing all possible contracts and selecting the combination of feasible contracts that would provide the highest valued use of the network.

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[1] William W. Hogan is the Thornton Bradshaw Professor of Public Policy and Management, John F. Kennedy School of Government, Harvard University, and Director, Putnam, Hayes & Bartlett, Inc., Cambridge MA. He serves as Research Director for the Harvard Electricity Policy Group. The author is or has been a consultant on electric market reform and transmission issues for British National Grid Company, General Public Utilities Corporation (working with the "supporting" companies of the PJM proposal), Duquesne Light Company, Electricity Corporation of New Zealand, National Independent Energy Producers, New York Power Pool, New York Utilities Collaborative, San Diego Gas & Electric Corp., Trans Power of New Zealand, and Wisconsin Electric Power Company. Hamish Fraser, Scott Harvey, Laurence Kirsch, Richard O'Neill and Susan Pope provided helpful comments and assistance. The views presented here are not necessarily attributable to any of those mentioned, and the remaining errors are solely the responsibility of the author.

[2] W. Hogan "Electricity Transmission Policy and Promoting Wholesale Competition," Initial Response to the Notice of Proposed Rulemaking Regarding Promoting Wholesale Competition Through Open-Access Non-Discriminatory Transmission Services by Public Utilities, Federal Energy Regulatory Commission, Docket No. RM95-8-000, Harvard University, August 7, 1995.

Transmission Congestion Contracts

The context for the creation of transmission congestion contracts (TCC) is a system of short-term transmission usage pricing based on locational marginal cost pricing. An independent system operator (ISO) determines the locational prices based on the actual dispatch and the bids of system users, and either buys and sells power at these prices or charges the locational differences in these prices for transmission of power from one location to another. For most transmission, large differences in locational prices would be dominated by the difference in congestion costs. All transmission usage would be charged based on these locational differences.

A general description of a TCC could be any vector of net loads in the grid. The typical discussion of TCCs presumes that the vector describes transmission of a fixed amount of power from a source to a destination in the network. This special case for transmission of "x" MW would be the vector

$$TCC = (0,.., -x_{source}, ..., x_{destination}, ...,0)^t.$$

This form of a balanced TCC always sums to zero. However, there would be no necessity to impose this balancing requirement on each individual TCC. All that would be required would be that the set of all TCCs would be simultaneously feasible and appropriately balanced.

The TCC would be denominated in the quantity of power input and output at various locations. This is similar to transmission from source to destination, intended to mean the actual flow of power, or at least specific performance on the locational delivery of the power. However, the TCC is not a contract for actual delivery of specific, identified power. The definition assumes that loads will be met either through actual delivery or through displacement. Hence, the actual power flows may be (very) different from the quantities embodied in the collection of TCCs. By contrast to a contract for physical flows, the TCC is a contract for payment of congestion costs. These payments are designed so that the user is economically indifferent between meeting the load through actual delivery or through displacement.[3]

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[3] There is much less to the distinction between physical and financial transmission rights than meets the eye. In the narrowest definition of strictly physical rights, no use of the transmission system would be allowed without obtaining in advance a matching "physical" reservation that would be acquired somehow in the initial allocation or the secondary market. But practical implementations provide that the reservations could be used either in the "physical" sense of matching actual transmission flows to reservations, or in a "financial" sense in that unused reservations would in effect be bought, sold and reconfigured based on opportunity cost pricing through a spot market coordinated through a bid-based economic dispatch by the ISO. In the presence of an active spot market, this trading of capacity reservations at opportunity cost prices makes the "physical" capacity reservation more like a "financial" contract. Whether we call these transmission instruments "capacity reservations" or "transmission congestion contracts" or something else is more a semantic than a substantive issue. How we organize the market, however, does matter because of the rather substantial transaction costs. Forcing people to think of, and treat, the transmission capacity reservations as narrowly defined physical rights that have to be reconfigured, constantly and explicitly, in

The short-term locational prices for the actual dispatch can be decomposed into three components relative to a reference bus: the price of generation at the reference bus, the marginal cost of losses relative to the reference bus, and the marginal cost of congestion relative to the reference bus. Let p_C be the vector of congestion prices for each bus. The contract between the ISO and the holder of TCC_i calls for a payment by the ISO of $p_C^t(TCC_i)$. For a balanced TCC_i from a location with a low congestion price to a region with a high congestion price, the TCC_i payment to the TCC_i holders would be positive, just compensating for the congestion cost of the price of transmission usage. In the reverse case, the TCC_i holder would make a payment to the ISO, returning the negative transmission usage charge paid by the ISO.[4] Hence, the TCC would not affect the dispatch or give the holder any control over the use of the transmission grid. However, in each case the holder of the TCC could perfectly hedge the congestion cost of transmission usage as though power had flowed according to the TCC but free of congestion cost.

In this sense, a balanced TCC is analogous to a futures contract for the spot price of transmission congestion, with a target price of zero. If the spot price of transmission congestion were more (or less) than zero, the TCC would exactly balance the spot price payment for the quantity covered by the contract. This TCC could be traded in a secondary market and would provide a contractual mechanism for long-term pricing of transmission in a competitive, open access electricity market.

Concurrent Auction

Consider first the case of a model of real power only, as in the DC-Load approximation. For this simplified case, define the net real power loads at each bus as the vector y_P of load minus generation.[5] The possible set of real power loads is constrained by the usual network load flow equations and a series of constraints. These constraints could include MW

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order to allow for schedules in the transmission system, would create a cumbersome and possibly unworkable system for the actual dispatch. Recognizing that economic dispatch reconfigures and trades these rights implicitly would capitalize on well-established principles of reliable dispatch and economic efficiency. For further details, see S. M. Harvey, W. W. Hogan and S. L. Pope, "Transmission Capacity Reservations and Transmission Congestion Contracts," Harvard University, June 6, 1996, (revised October 14, 1996 and filed with the FERC as part of submission of William W. Hogan, Capacity Reservation Open Access Transmission Tariffs Response to FERC Notice of Proposed Rulemaking, Docket No. RM96-11-000, Washington, D.C., October 21, 1996).

4 This is the "obligation" form of the TCC. If the payments were discretionary, then the holder would never make a payment to the ISO for the case of a negative congestion difference. This would be the "option" form of the TCC. The option form would require a substantially more complicated feasibility test, and is not considered here. For further discussion, see S. M. Harvey, W. W. Hogan and S. L. Pope, "Transmission Capacity Reservations and Transmission Congestion Contracts," Harvard University, June 6, 1996, (revised October 14, 1996).

5 If the demand for power at each location or bus is "d" and the generation is "g", let y= d-g be the vector of net loads at each bus. The sign convention reverses the approach in Schweppe et al., but simplifies the interpretation of prices. F. C. Schweppe, M. C. Caramanis, R. D. Tabors, and R.E. Bohn, Spot Pricing of Electricity, Kluwer Academic Publishers, Norwell, MA, 1988.

limitations on line flows in both pre- and post-contingency conditions. There may be many of these constraints, including complicated limitations involving multiple lines and locations. The only requirement is that the constraints can be specified in terms of the net loads.[6] For the present discussion, all of these constraints are collected in the function K(.), with the feasible net loads characterized by:

$$K(y_P) \leq 0.$$

If congestion payment obligations must be met from the congestion revenues collected by the ISO, the TCCs must be feasible, in the sense that $TCC = \sum TCC_i$ and $K(TCC) \leq 0$. That feasibility would be necessary is clear from the case where the only transmission usage is from the net loads implied by the TCCs. In the DC-Load case, where all the constraints K(.) are linear, feasibility is also sufficient to assure this revenue adequacy condition. If the actual usage of the system is y_P^*, and TCC is feasible, then we know that

$$p_C^t(y_P^*) \geq p_C^t(TCC) \quad .$$

In other words, the congestion payments collected by the ISO for actual use of the system would always be at least as large as the congestion payments made to the holders of the TCCs.[7] Hence, the ISO would always be hedged.[8] As long as the grid is the same, and only load patterns are changing, the ISO would be able to honor the TCC commitments.[9]

Presumably the use of a TCC would be as a hedge for the congestion component of transmission costs for a long-term power sale. The price that users would be willing to pay for a TCC would be limited by the economics of the power deal. Suppose that this or some other economic assessment permits users to evaluate TCCs. This is equivalent to asking the user to set a value for long-term transmission between locations. Following the motivation of competitive markets, an auction would provide an equilibrium allocation of the TCCs at market prices, with the assignments to the highest valued uses.

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[6] The distinction refers to the common practice of using "interface" constraints limiting the power flow on particular lines. The "limit" often is a projection assuming small deviations from a target value of net loads, say t_P. In effect, the constraint can be interpreted as being an approximation of the form of $\mathcal{K}(y_P,t_P)\leq 0$, with t_P fixed and y_P close to t_P. If y_P differs from t_P, then the "limit" is changed and a new target is set. For our purposes, we would interpret the constraint as $K(y_P) = \mathcal{K}(y_P,y_P)\leq 0$.

[7] W. Hogan, "Contract Networks for Electric Power Transmission," Journal of Regulatory Economics, Vol. 4, September 1992.

[8] In principle, speculators could offer any amount of TCCs, for a price, but the ISO would not be required to accept any exposure.

[9] There may be excess congestion rentals after making all the required payments under the TCCs. These payments should not be left with the ISO and could be redistributed under a sharing formula, perhaps among the owners of the TCCs.

The infinite array of possible feasible TCCs makes it difficult to define in advance the availability of any subset of the contracts; all the TCCs would interact in the network, and the many TCCs would be separate products that must be auctioned concurrently.[10] However, it is possible to structure a concurrent auction that simultaneously defines and awards the TCCs. A description of the network and its constraints provides a characterization of all possible combinations of TCCs. Following the logic of economic dispatch, the market equilibrium for these multiple products will be equivalent to the result of a central evaluation of bids for the TCCs under the assumption that the participants have an incentive to bid their maximum willingness to pay. If all winning bidders would pay the market clearing price for their TCCs, and there were enough bidders so that no bidder would know in advance which bid would set the market price, then the participants would have an incentive to bid their maximum willingness to pay, and the centralized concurrent auction of TCCs would achieve the market equilibrium.

The resulting TCC concurrent auction optimization problem would be closely related to the corresponding economic dispatch problem. Suppose that we describe a bid for capacity by bidder "i" as a maximum quantity $TCCBID_i$, with vector bid_{Pi} that defines the real power inputs and outputs per unit of the TCC. The accompanying maximum price would be $Pbid_i$. Let x_i be the allocation of TCC_i. Then under the DC-Load assumption of ignoring losses, the adaptation of the optimal allocation of TCCs problem becomes:

$$\max_{x_i \geq 0, y_P} \quad \Sigma \, Pbid_i x_i$$

subject to

<u>Bid Definition</u>

$$x_i \leq TCCBID_i, \quad \text{for all } i,$$
$$y_P - \Sigma \, bid_{Pi} x_i = 0 \quad ;$$

<u>Kirchoff's Laws and System Operating Limits</u>

$$K(y_P) \leq 0 \quad .$$

The solution to this problem will yield the optimal TCC awards. Furthermore, under the assumption that the bids represent the maximum willingness to pay, the dual solution yields the market clearing prices for the bids.[11] In particular, the corresponding dual variables and optimality conditions would include:

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[10] W. Hogan, "An Efficient Concurrent Auction Model for Firm Natural Gas Transportation Capacity," <u>Information Systems and Operational Research</u>, Vol. 30, No. 3, August 1992.

[11] R. P. O'Neill and W. R. Stewart, Jr., "A Linear Programming Approach for Determining Efficient Rates for Public Utility Services," <u>Advances in Mathematical Programming and Financial Planning</u>, Volume 3, JAI Press, 1993, pp. 163-178.

$$\theta_i + (\lambda_P)^t bid_{Pi} \geq Pbid_i,$$

$$\lambda_P - \nabla K \mu = 0 \ ,$$

$$\theta_i, \mu \geq 0 \ .$$

Apparently the opportunity cost of congestion for each location would be defined by the vector λ_P, and the opportunity cost for a particular award of TCC_i would be $(\lambda_P)^t bid_{Pi}$. By the principles of complementary slackness, for any positive award of a TCC, the marginal opportunity cost price would be $P_{TCCi} = (\lambda_P)^t bid_{Pi}$ and the bidder's surplus or rent would be $\theta_i = Pbid_i - P_{TCCi}$. Since this surplus is always positive, we see that P_{TCCi}, which would be the market clearing TCC award price paid, would never be greater than the bid price.[12]

Example Auction

The three bus example network in Figure 1 illustrates the elements of a concurrent auction of TCCs. Here the three buses are connected by three identical lines. We follow the DC-Load assumption and ignore losses. There is only one constraint which limits the flow of power on the line between buses 1 and 3 to a maximum of 600 MW. The various actors in the market have identified two types of TCCs that would have value, from bus 1 to bus 3 and from bus 2 to bus 3. The assumption is that there are many bidders with different maximum evaluations of the amount they would pay for the respective TCCs. These evaluations become bids in the concurrent auction. The collection of all the bids appears as a bid curve for each type of TCC. For simplicity, the bids are assumed to be the same for both types of TCCs, but any bids would be allowed.

The three bus example is the simplest case that includes the effects of loop flow and network interactions. However, there is no necessary connection between the definition of the TCCs and the ownership of the lines between buses. The example could be expanded by adding other lines and buses. The TCCs would still be defined from one bus and to another bus, without any requirement that there be a direct link between the two buses.

Here the highest bid is at 6 cents, and the bid prices decline to zero at the level of 1200 MW. The objective is to find the combination of awards that maximizes the area under the bid curves, which is the sum of the value of the successful bids. In principle, all the transmission capacity could be awarded to TCCs from either source. If all the TCCs came from bus 1, then the line limit would constrain and the maximum award possible would be 900 MW with a price of 1.5 cents. The value would be the area under the bid curve, 1.5(900) + 4.5(900)/2

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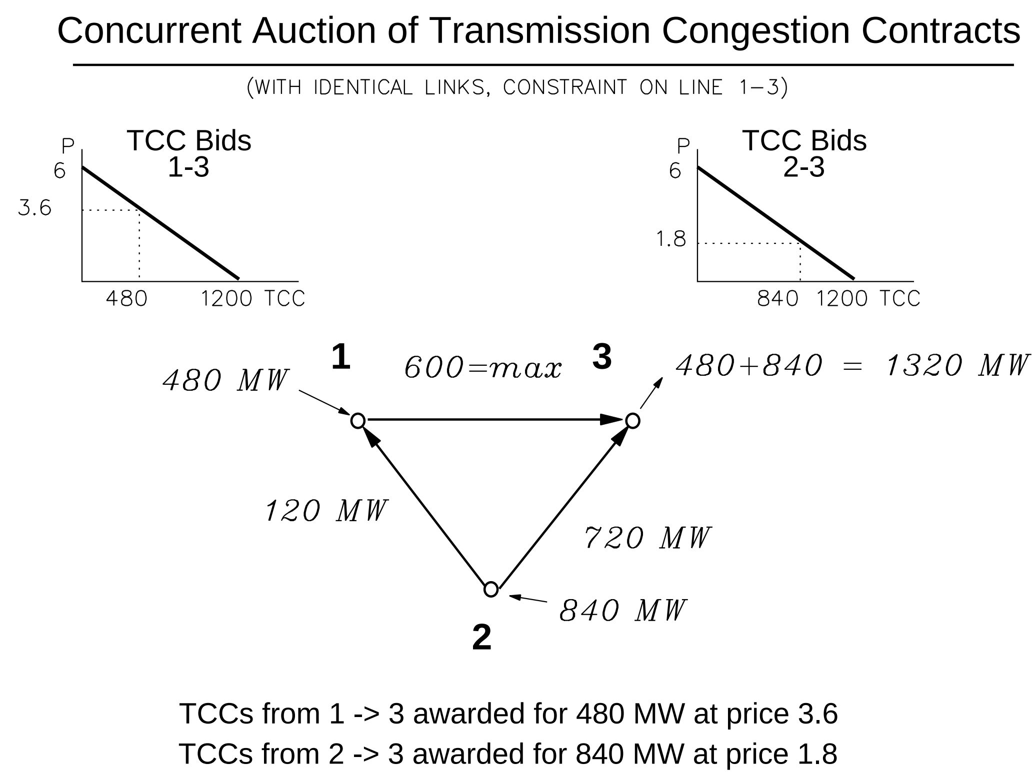
[12] Note that either the maximum price bids, $Pbid_i$, or the TCC award prices could be negative, implying that the holder would be paid in advance to take on the financial obligation for transmission flow that apparently would increase the overall capacity of the system. For example, a TCC might provide counterflow in parts of the network that increased the capability to award other TCCs.

Figure 1



= 3375. If all 1200 MW of bids for TCCs from bus 2 were accepted, the price for these would be zero and there would be excess capacity. The value for these awards would be the area under the bid curve, 0(1200) + 6(1200)/2 = 3600. Neither extreme would provide the highest valued use of the transmission grid. However, the concurrent auction formulation takes into consideration all the bids and the interactions in the network to find the maximum value award and the associated market clearing prices for the TCCs.

The result of the concurrent auction in Figure 1 awards 480 MW for TCCs from bus 1 to bus 3 and 840 MW of TCCs from bus 2 to bus 3. The market clearing prices for the respective TCCs are 3.6 cents and 1.8 cents. The value for these awards would be the area under the bid curves, 3.6(480) + 2.4(480)/2 + 1.8(840) + 4.2(840)/2 = 5580. In this simple case, the ratio of the prices is just the inverse of the tradeoff between the two types of TCCs. In order to maintain feasibility, given the constraint on the line from 1 to 3, each MW from bus 1 to bus 3 displaces 2 MW from bus 2 to bus 3.[13]

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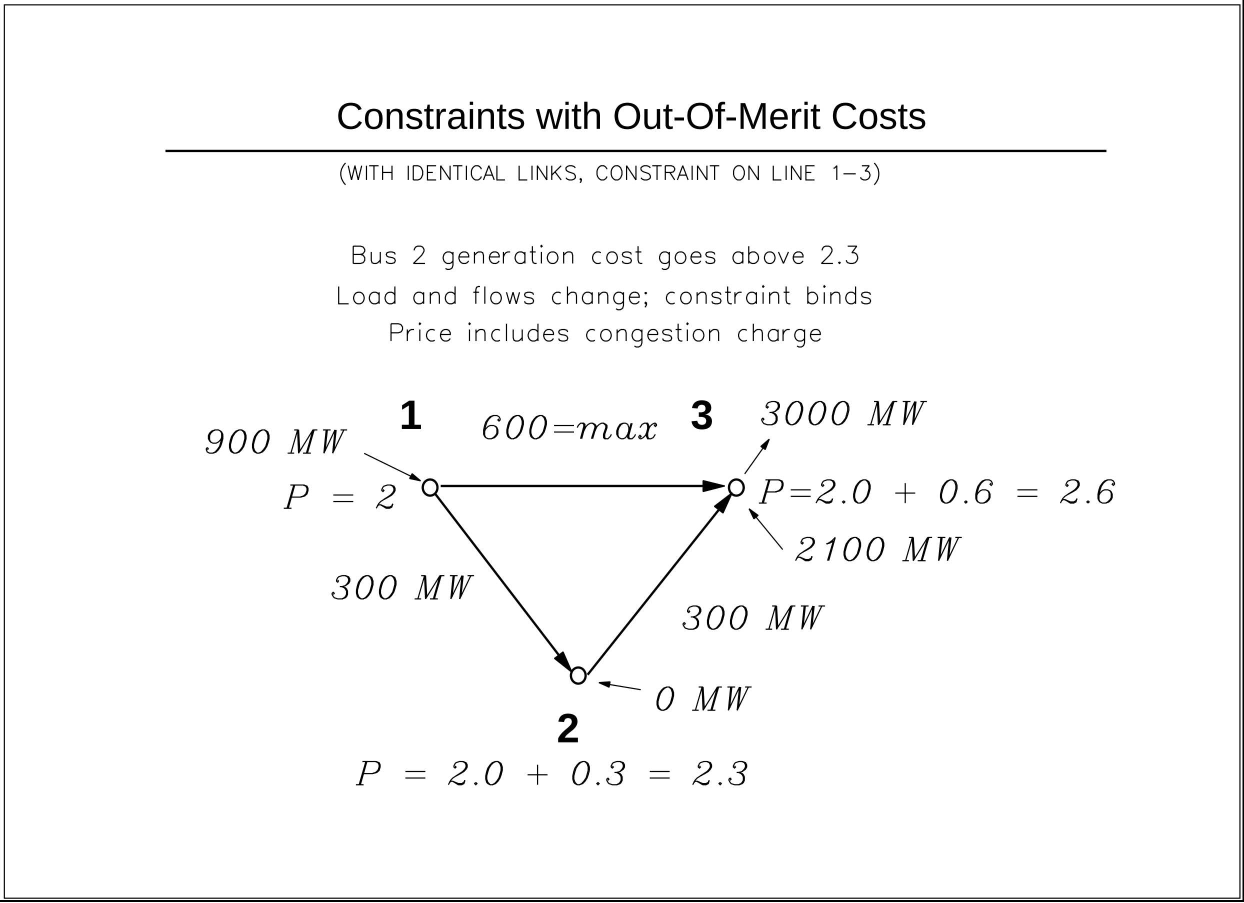
[13] The bid vectors are $(-1, 0, 1)^t$ for the TCC from bus 1 to bus 3 and $(0, -1, 1)^t$ from bus 2 to bus 3. The values for the various dual components include: $\nabla K = (0, 1/3, 2/3)^t$; $\mu = 5.4$; $\lambda_P = (0, 1.8, 3.6)^t$.

Figure 2



The existence of the TCCs tells us nothing about the total price of power that might be arranged under contract or that would be determined in the spot market. Apparently the winning TCC bidders believe the average differences in the prices between buses will be at least as large as the concurrent auction award prices. However, with these TCCs in place, the holders would have a perfect hedge for the spot price of transmission. If the spot price of transmission is high, then the TCC congestion payment would compensate the holder for the spot price. However, the spot price of transmission could be higher or lower than the cost of the TCC.

For example, suppose that the actual dispatch conditions conform to those in Figure 2 where economic dispatch leads to much of the load at bus 3 being supplied by generation at bus 3 with a cost of 2.6 cents. Here the generation at bus 2, where the opportunity cost is 2.3 cents, is too expensive to run, and the remaining generation at bus 1 is supplied at a price of 2 cents.

Everyone using the transmission grid is paying at these short-term prices. Those buying and selling through the ISO employ the appropriate locational prices. Those transmitting power from one bus to another pay the spot price of transmission equal to the difference in the locational prices. The total net usage charge collected by the ISO is 3000(2.6) - 2100(2.6) -

900(2) = 540. The difference in congestion charges between bus 1 and bus 3 is 0.6, requiring a payment of 480(0.6) to the holders of TCCs from bus 1 to bus 3. The difference in congestion charge from bus 2 to bus 3 is 0.3, requiring a payment of 840(0.3) to the holders of TCCs from bus 2 to bus 3. The total payment to TCC holders is 480(0.6) + 840(0.3) = 540. Hence, the total congestion payments for use of the grid are large enough to pay the TCC obligations, even though the dispatch and economic conditions have changed.

For the holders of TCCs from bus 1 to bus 3, the effective cost of power delivered at bus 3 is 2 cents, the same as the price at bus 1; for the holders of TCCs from bus 2 to bus 3, the effective cost of power delivered to bus 3 is 2.3 cents, the same as the price at bus 2. The holders of the TCCs have a perfect hedge for the spot price of transmission congestion. Of course, in this case the holders paid more for the TCCs than they were worth for this particular dispatch. With economic conditions changing, presumably there would be other periods when congestion could be greater than the price paid for the TCC. Whether the average congestion costs would justify the price of the long-term protection is uncertain, and would be a business risk in the competitive market. However, the TCC holders would be assured of getting what they paid for: long-term protection from the uncertain congestion costs of transmission, no matter what the changing pattern of the loads.

Including Losses and Reactive Power

The generalization of the TCC auction to account for the effects of losses, reactive power and the non-linear AC-load formulation follows in a natural way. Here the TCC would be defined in terms of both real and reactive power net loads. However, the model must be expanded to account for losses. Because the TCC calls only for payment of congestion rents, which are by definition set to zero at the reference bus, the losses or other imbalances can be treated as being met at the reference or swing bus, as the quantities y_{Ps} and y_{Qs} needed to satisfy the power balance equations.[14]

The constraints on the vector net real loads y_P and reactive loads y_Q would now become $K(y_P, y_Q, y_{Ps}, y_{Qs})$ and include pre- and post-contingency MVA line flow limits as well as bus voltage magnitude bounds. Under certain assumptions for this more general case, a similar revenue adequacy condition would apply: for any feasible set of TCCs and any actual dispatch, the short-term congestion payment obligations under the TCCs would always be no

[14] The convention to apply the TCC idea only to congestion is not required. Losses could be included, at the cost of requiring some unbalanced TCCs. See S. M. Harvey, W. W. Hogan and S. L. Pope, "Transmission Capacity Reservations and Transmission Congestion Contracts," Harvard University, June 6, 1996, (revised October 14, 1996).

more than the congestion revenues collected by the ISO.[15] Hence, maintaining a feasible set of TCCs would be necessary for this riskless hedge, and under market equilibrium conditions would be sufficient. The objective of the auction is to find the highest valued allocation of the feasible TCCs.

The corresponding non-linear concurrent auction problem would become:

$$\max_{x_i \geq 0,\ y_P,\ y_Q,\ y_{Ps},\ y_{Qs}} \quad \Sigma\, Pbid_i x_i$$

subject to

Bid Definition

$$x_i \leq TCCBID_i, \quad \text{for all } i,$$
$$y_P - \Sigma\, bid_{Pi} x_i = 0 \quad ,$$
$$y_Q - \Sigma\, bid_{Qi} x_i = 0 \quad ;$$

Kirchoff's Laws and System Operating Limits

$$K(y_P, y_Q, y_{Ps}, y_{Qs}) \leq 0 \quad .$$

As before, the dual constraints and variables would define the market clearing prices. The dual problem includes:

$$\theta_i + (\lambda_P)^t bid_{Pi} + (\lambda_Q)^t bid_{Qi} \geq Pbid_i,$$

$$\lambda_P - \nabla K_P \mu = 0 \quad ,$$
$$\lambda_Q - \nabla K_Q \mu = 0 \quad ,$$

$$\theta_i, \mu \geq 0 \ .$$

Now the market value of congestion for each location would be defined by the vectors λ_P and λ_Q, and the opportunity cost for a particular award of TCC_i would be $(\lambda_P)^t bid_{Pi} + (\lambda_Q)^t bid_{Qi}$. By the principles of complementary slackness, for any positive award of a TCC, the marginal opportunity cost price would be $P_{TCCi} = (\lambda_P)^t bid_{Pi} + (\lambda_Q)^t bid_{Qi}$ and the bidder's surplus or rent would be $\theta_i = Pbid_i - P_{TCCi}$. Since this surplus is always positive, the market clearing TCC award

[15] Whenever there is a spot-market equilibrium set of prices, the revenues from the actual dispatch will exceed the payments required under the TCCs for the general case including losses. In general, there may be conditions where there is no set of equilibrium prices available, due to non-convexities in the optimal dispatch problem. In this (probably rare) case, central dispatch would be required to achieve a welfare maximizing solution, but the ISO might not be able to guarantee the full revenue for the TCCs. For further discussion, see S. M. Harvey, W. W. Hogan and S. L. Pope, "Transmission Capacity Reservations and Transmission Congestion Contracts," Harvard University, June 6, 1996, (revised October 14, 1996).

price paid would never be greater than the bid price.

Extensions

The TCC concurrent auction optimization problem is essentially a special case of the non-linear optimal power flow dispatch problem. The complication is only in the addition of a few linear side constraints -- the "Bid Definition" constraints -- which would be easy to implement. Although optimal power flow models may be difficult to use in real time for fully automated control of the system, this auction calculation need be repeated only at infrequent intervals when there is to be an expansion of the system or trading among the existing TCCs.

Further extensions of the complexity of the auction could be accommodated. For example, bidders may submit multiple bids, and then apply constraints on the joint awards across these bids. Any set of added linear constraints on the bidders set of x_i variables should be easy to incorporate, with more non-linear constraints depending on the availability of software to solve the problem. Presumably any bidder's constraints on its own bids could be accommodated as long as zero (i.e., no award) would be a feasible solution to the set of side constraints.

The formulation of the concurrent auction model is quite general, but it presumes the ability of the bidders to define their preferences. In the case of real power flows, losses would be small and it would be reasonable to expect the bidders either to define imbalanced bids to account for losses or to accept the losses computed as necessary to balance at the reference bus. For reactive power, however, balancing by individual TCCs is less reasonable and the different levels of reactive power needed to support a TCC would be more difficult to determine. Here an approximation may be obtained by incorporating a range of reactive net loads that would accompany each TCC bid. Formally this could be accomplished through multiple bids, with constraints across bids. Or a single bid could include maximum and minimum levels of reactive net input associated with a real power bid.

The concurrent auction could be implemented as a single-pass system or as part of a sequential auction. The concurrent auction deals with the interactions in the network, but not with interactions with generation and load contracts that might be relevant in determining the bid maximum prices, $Pbid_i$. In a sequential version of the concurrent auction, the bids could be revised for a sequential repetition of the auction for a fixed number of cycles or until no bids changed. Subject to certain limitations on the bid changes to avoid strategic behavior and cycling, this could provide the auction participants with additional market information in setting their maximum bid prices.[16]

Note that this auction model allows for consideration of existing TCCs. These can be

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[16] This has been suggested, for example, in the New York Power Pool proposal. See "Responses to Questions Regarding the Report on NYPP Proposed Market Structure," New York Public Service Commission filing by the New York Power Pool, January 3, 1997, questions NYPP-103; PSC-19 through NYPP-108; PSC-24.

included simply as bids, with the minimum selling price treated as the bid. If the existing TCC is not included in the award, then it has been sold back to the market. The sales price is still P_{TCCi}, but for variables not included in the optimal solution the principle of complementary slackness guarantees that this sales price would be at least as high as the bid price. Hence, for TCCs which the holders do not wish to sell at any price, a sufficiently high minimum selling price will guarantee the TCC is preserved, and the holder of the TCC would formally sell and buy the TCC at the market price, leaving no change.

The concurrent auction formulated above is for a single, static set of TCCs. This model could be applied to separate periods to allow for time varying TCCs, such as peak and off-peak. In the UK, for example, power contracts are written that can differ in prices and terms for each of the 8760/4=2190 four hour long "electric forward agreement" (EFA) periods each year. In principle, the concurrent auction model could be extended to include multiple periods with inter-temporal constraints. For instance, bids may be for multiple periods, with different bids covering different periods. The network and inter-temporal constraints could assure feasibility, with the objective function specified as the present value of the bids. For the DC-Load formulation, even for large networks this optimization problem would be no more complicated than the dispatch problems now solved routinely for all 8760 hours of the year. For the full non-linear problem, current software can solve a single period optimization in a few minutes for a large network. The extension to multiple periods is possible, but remains to be demonstrated.

Conclusion

The complex interactions in real electric networks make it impossible to define the capacity for point-to-point reservations or transmission congestion contracts in the simple additive manner that would be possible for a radial system. However, it is possible to characterize the constraints on the feasible set of transmission flows, and this is done as a regular part of economic dispatch. The extension to operate a spot-market using a bid-based economic dispatch suggests the parallel extension to a concurrent auction for awarding a feasible set of transmission congestion contracts. The same optimal dispatch formulation, extended to include a set of linear side constraints to define the bids, allows bidders to express preferences for transmission congestion contracts and then the ISO to determine the simultaneous set of awards and market clearing prices that maximize the value of the awards as expressed in the bids. Hence the auction can implicitly include all possible awards, without any necessity of forecasting a particular set of loads or transmission congestion contracts.