Grid Investment: Can a Market Do the Job?

The complex externalities associated with grid modification have convinced many that a regulated body must plan grid modifications. But an appropriate rule for allocating "transmission congestion contracts" to those who provide grid improvements might allow a decentralized, profit-driven "market" to carry out this difficult function efficiently.

James Bushnell and Steven Stoft

James Bushnell *is a research associate at the University of California Energy Institute. He holds a Ph.D. in industrial engineering and operations research from the University of California at Berkeley.* **Steven Stoft** *is a research associate at the University of California Energy Institute and is an economist at the Lawrence Berkeley National Laboratory. He holds a B.S. in engineering math and a Ph.D. in economics from the University of California at Berkeley.*
The California Energy Commission partially supported the research reported on in this article.

Recently the incentives provided for grid investment by the nodal pricing of transmission have been hotly debated. In particular, "Transmission Congestion Contracts" (TCCs) have been faulted for inducing investors to alter the grid in ways that harm the network as a whole. While such conclusions are plausible, the arguments supporting them have not been.

In order to deduce the incentives provided by TCCs one *must* specify the rule by which investors will be assigned TCCs when they complete a grid alteration. Without specifying this rule, deducing TCC incentives is like deducing the incentives of employee bonuses without knowing the rule by which they are handed out. Unfortunately, both Oren et al.[1] and subsequent letters debating TCCs do not even attempt to specify such a rule. Similarly, when TCCs were proposed as an incentive mechanism,[2] such a rule was hinted at but never specified.

This article will give an exact specification for a TCC allocation rule and will report several results concerning investment incentives implied by that rule.

Many of the disagreements in this discussion are illusory. There is much talk of misusing a "transportation analogy"[3] for transmission, but this mistake is rarely committed.

Oren et al. show that TCCs are the equivalent of financial forward contracts. In fact, a rule for allocating TCCs could also be implemented as a rule for allocating forwards.

It is generally agreed that if the pool keeps collections from nodal spot price differences, this will provide incentives for mispricing. But this "merchandising surplus" can be easily and usefully disposed of by reducing access fees, which have detrimental incentives.

Lastly, it is agreed that TCCs may have negative value. However, such TCCs are important because they make it possible to "punish" those whose investments impair the grid.

The only real controversies are what form of market will efficiently generate optimal prices, and how to induce efficient investment in the grid. This article is concerned solely with the latter.

I. Allocating TCCs for Grid Alterations

The rule for allocating TCCs to network investors is of crucial importance because much of the incentive to expand the network derives from this allocation. Changes in the modifier's nodal prices provide the other incentive. This section makes explicit a rule for allocating TCCs that is based upon the feasibility of corresponding dispatches.

A. TCCs and Dispatches

Recall that TCCs can be defined between any pair of nodes by specifying a fixed directed contract quantity, R. Specifically, the TCC defined by R_{ij} implies a payment from the pool to its owner of $R_{ij}(p_j - p_i)$, the contract quantity times the nodal price difference. The concept of the TCC was developed to serve as a hedging instrument for the locational price difference between two nodes in the network. A marketer who wants to sell R megawatts of power to the pool at i and buy it at j can eliminate its price risk by purchasing an R_{ij} TCC.

If the pool keeps collections from nodal spot price differences, this will provide incentives for mispricing.

This fact illustrates the natural correspondence between TCCs and actual power injections. Similarly, any set of TCCs corresponds to a dispatch of the system. The supply, q_i, into node i corresponding to a set of TCCs is given by the following sum over all TCCs in the set:

$$q_i = \Sigma_j R_{ij} - \Sigma_j R_{ji}$$

Repeating this process for every node produces the complete corresponding dispatch.

B The Feasibility Rule for Allocating New TCCs

The "feasibility rule" allows a network expander to adopt any new set of TCCs he wishes, so long as the resulting set of outstanding TCCs is feasible under the new grid configuration. By outstanding TCCs, we mean all those that the pool is obligated to support financially. To assess feasibility, look at the dispatch that corresponds (as defined above) to the set of outstanding TCCs. If this dispatch does not violate any physical or contingency constraints, then the set of TCCs is considered feasible. Thus the "feasibility rule" ensures that the existing set of TCCs always corresponds to a feasible dispatch.

Feasibility Allocation Rule: The reward for an expansion of the network is any set of rights, $\{dR_{ij}\}$, of the expanding agent's choosing, provided that $\{R\} + \{dR_{ij}\}$ is feasible, and where $\{R\}$ is the set of previously allocated contracts.

Because TCCs are *financial* property rights which do not place restrictions on the actual dispatch of the system, the feasibility of TCCs is not required for network reliability, but TCCs do place a financial obligation on the pool. However, Hogan has proven that if the allocated TCCs are restricted to be a feasible dispatch, then the payments made to TCC holders will not exceed the pool's marketing surplus. [4]

Oren et. al. raised the concern that the pool may not dispatch optimally if it is allowed to keep this surplus between grid revenues and TCC payments. They concluded that "the feasibility condition (3) in Hogan's 1992 formulation[5] is unnecessary and meaningless" since it was "only intended to serve as a solvency condition for the market maker." However, as the next section explains, the feasibility rule plays an absolutely crucial role in determining grid investment incentives.

II. Investment Incentives

Although we have defined the rule for allocating transmission contracts, this does not determine how they are distributed among market participants because TCCs are tradable. Lacking a theory of this trade, we must specify something about the distribution of TCCs in order to prove anything about investment incentives. As it turns out, the needed distribution property is that "TCCs match dispatch."

A. Group Matching of TCCs with Dispatch

First consider a generator and a load with a bilateral contract for 100 MW from A to B. If they exactly fulfill this contract and if they also own a TCC for 100 MW from A to B, then we say that their dispatch matches their TCC. We would say this whether the TCC was owned by the generator or by the load. Thus the concept of contracts matching dispatch is one that we apply at the group, not the individual, level.

Including another generator and another load trading 100 MW between A and B, and assuming any one party owned a 200 MW TCC from A to B, we would still say that for this group, TCCs match dispatch.

B. 'Complete Contracting'

The strongest form of contract matching is on an individual level. We will call this *complete contracting*. It implies that the TCCs have been combined with contracts for differences so that both generators and demanders can hold forward positions corresponding to their own part of the dispatch. As a little algebra would show,[6] contracts for differences can effectively serve this purpose.

The feasibility condition in Hogan's 1992 formulation plays an absolutely crucial role in determining grid investment incentives.

C. Incentives Against Detrimental Investment

With these definitions we may state the basic results concerning the incentives for investment in the grid under a contract network regime.[7] All of these results assume that TCCs are awarded to modifiers of the grid according to the "feasibility rule" for TCC allocation.

Incentive Result #1: If contracts match dispatch for the system as a whole, then anyone who makes a detrimental modification to the grid will receive new contracts that will have negative value.

In a market-oriented approach to investment this is an important property. It says that if TCCs collectively correspond to the dispatch, then although any outside party can freely enter the market for transmission and build a new line (or tear down an old one), no such party can ever gain financially from making a grid modification that reduces the net benefit of the system as a whole. This result stands in sharp contrast to the investment incentives provided by the "link-based" rights examined by Oren et. al.

But what about existing players? The answer is ambiguous since the negative value of the new contracts might be outweighed by the changes in value of the *existing* contracts held by a particular player. However, stronger assumptions lead to stronger results.

Incentive Result #2: If contracts match dispatch for the system as a whole, then no group whose contracts match its dispatch will have a financial incentive to make a detrimental modification of the grid.

Result #2 assures us that no insider nor any group of insiders will find economic gain in a detrimental modification, provided that the group's contracts match its dispatch. This result easily extends to the most optimistic result.

Incentive Result #3: If the system is *completely contracted*, then no individual or group will have a financial incentive to make a detrimental modification of the grid.

D. Incentives For Beneficial Investment

The incentives for beneficial investments come from two sources: the desire of the investor to use the investment, and the value of the TCCs that are awarded according to the feasibility rule. Oren et al. point out that the rewards from TCCs will be insufficient to cover the cost of the grid investment, and this seems likely. But that does not mean it will be necessary to impose access fees in order to pay for grid investments under a TCC system.

The main reason to build lines will be to use them, and the profit from using them will cover the cost of building them if they are good investments. The uncertainty related to future congestion on these lines may reduce the incentive to build new lines. However, TCCs ensure that investors recover these congestion charges and that they do so without distorting the incentives that are properly induced by those charges.

The only difficulty with the incentive for beneficial investment comes from the fact that lines can benefit many parties. Consequently, in order to accomplish such a grid expansion efficiently through a market mechanism, it is necessary that all the benefiting parties cooperatively make the investment. Unfortunately, because expansion costs are nonlinear, there may well be incentives towards free riding. It has been claimed that because transmission is relatively cheap this problem will not be substantial, but this has not been demonstrated.

E. The Problem of Matching Contracts

As was just demonstrated, the disincentive for detrimental investment comes from matching contracts with dispatch. Is such matching at all plausible? The answer is that several factors point in this direction, though they provide no guarantee.

There is absolutely no possibility that transmission congestion contracts will exactly match dispatch.

First, it must be admitted that there is absolutely no possibility that TCCs will exactly match dispatch. But as long as the match is fairly close, on average, incentives should be reasonably close to what is assured by our results. Even to get such an approximate match, fairly complex time specifications for the TCCs will be needed.

On the other hand, it can be shown that an investor can do no better when choosing an awarded set of TCCs than to choose a set that will bring the total set of TCCs to the point of exactly matching the total dispatch. Because of this, if any one investor fails to maintain the match, the next investor (no matter how small his investment) will have an incentive to fully restore matching at the system level.

Still, this does not ensure matching at the individual level. An investor may well take TCCs that cover the dispatch expected by others. So an investor may start out owning TCCs that correspond to someone else's dispatch. Generally these will be more valuable to the party whose dispatch they correspond to because, for the investor, they are a speculative investment, while if owned by the dispatching party they would constitute a hedge against congestion charges. Thus investors will tend to redistribute contracts by selling them to the appropriate parties. In spite of these tendencies, the likely distribution of TCCs needs further study.

III. Examples

Oren et al., using a three-node, three-line network, demonstrated some perverse investment incentives provided by "link-based" transmission rights. They speculated that TCCs have "implications that are not altogether different" from these link-based rights problems. Here, we will use an equivalent network (with simpler parameters) to illustrate the implications of the feasibility rule for the effects described by Oren et al.[8]

The base case is shown in **Figure 1B**. Node 3 is a demand node, with an inelastic demand of 9 MW. There is generation located at nodes 1 and 2, with marginal costs given in **Figure 1A**.

For simplicity, we assume that all three lines initially have equal impedances. Two-thirds of the power injected at nodes 1 or 2 will therefore flow over the respective direct links to node 3, while one-third of that power will take the longer path through the other generation node. We assume that lines 1-3 and 2-3 have a capacity of 10 MW, while line 1-2 has a capacity limit of only 1 MW.

Figure 1B gives the optimal dispatch, line flows, and nodal prices for the base case. Generator 1 is the least cost supplier but its output is restricted by the constraint on line 1-2. As in the example of Oren et al. the flow along line 2-3 is from a higher to a lower price node. Therefore TCC R_{23} would have a *negative* value which its owner would like to eliminate.

Assume first that the set of TCCs matches the flows of Figure 1B. The owner the R_{23} contract could not simply give up this TCC, since the remaining contracts would imply a dispatch of 6 MW into node 1, 5 MW out of node 3, and 1 MW out of node 1. This dispatch is infeasible.

A. Eliminating Line 2-3

Assuming that the owner of the R_{23} contract has no other position in the market, he can profitably dispose of it by eliminating line 1-2. He could then select a 4 MW R_{32} contract which would offset the R_{23} contract.[9] The resulting corresponding dispatch of (q_1=6, q_2= 1, q_3= 5) would be feasible, so such a contract allocation would be allowed.

Figure 1C demonstrates that the destruction of line 2-3 in fact hurts the network. The cost of supply increases by 2 MW x 4¢ (on average) at node 1 and decreases by 2 MW x 3.6¢ at node 2. Thus, as Oren et al. suspected, TCCs can give an incentive to eliminate a useful line. This is due to the fact that the owner of the TCC was assumed to have *no* matching dispatch.

Instead assume that the TCCs *do* match dispatch for the relevant decision makers. Take, for instance, a pair of traders with a CFD who are trading 3 MW from node 2 to 3 and own a 3 MW R_{23} contract. Cutting line 2-3 would allow the elimination of R_{23} for a savings of .3¢ x 3 MW. There is no gain or loss at node 2 because marginal cost is constant, but there is a loss of 1.7¢ x 3 MW at node 3 from the price increase. Therefore, when TCCs match the injections of the group in question, the owner of the negatively valued TCC no longer has an incentive to eliminate this beneficial link.

Even when the owner had an incentive to eliminate the line, it

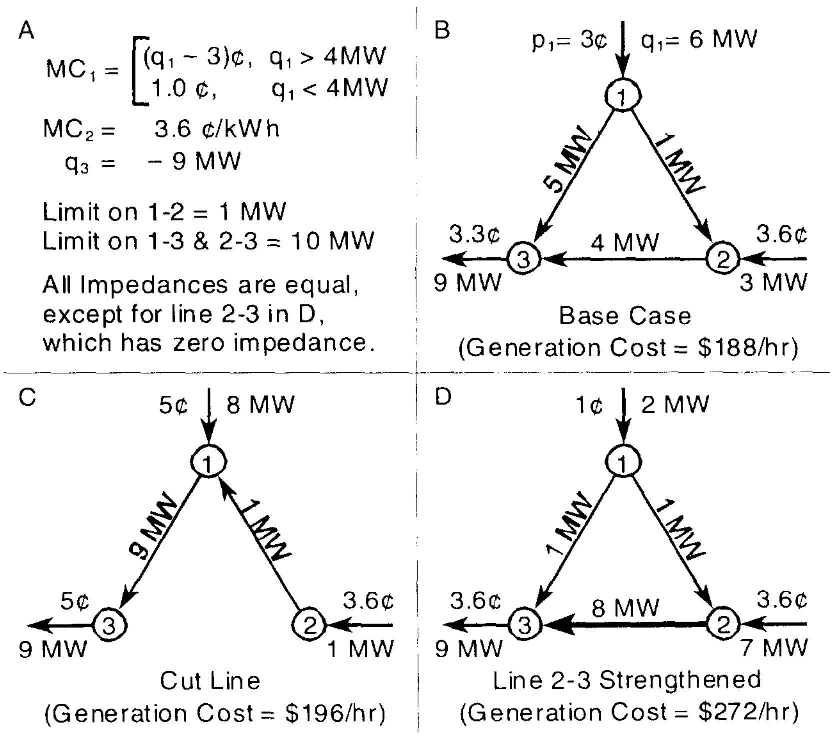

Figure 1: Three-Node Network Example

should be noted that he would have an even stronger incentive to sell his negatively valued TCC to those who benefit from that line.

B. Strengthening Line 2-3

The other detrimental grid investment examined by Oren et al. was the lowering of the impedance of line 2-3. To illustrate our points, we examine the extreme case of such an action: the lowering of the impedance of line 2-3 to essentially zero.[10] The optimal dispatch of such a network is shown in **Figure 1D**.

With line 2-3 having essentially no impedance, injections at 3 will flow directly to node 1, and provide no counter flow on the congested line 1-2. In our example, as in that of Oren et al., the value of R_{23} increases. In our case it increases to zero as the price difference between nodes 2 and 3 vanishes.

Oren, et al., did not, however, consider the allocation of any *new* contracts that would result from such an investment. Assume once again that the initial allocation of TCCs matched the flows in Figure 1B, (R_{13}=5, R_{12}=1, R_{23}=4). After line 2-3 is strengthened, this set of TCCs is no longer feasible. The grid investor must accept a new set of contracts that, when added to the original set, makes the total set feasible under the new network configuration.

In fact, the *best* set of *new* TCCs satisfying this allocation rule is the set that makes the *total* match the new dispatch. This set is (R_{13}= – 4, R_{12}=0, R_{23}=4). At the new nodal prices shown in 1D, the value of this set of contracts is – 4 MW x 2.6¢ = $104/hr. ($R_{12}$ and R_{23} have zero value.)

Thus the investor is forced, by the allocation rule, to accept a set of TCCs with *negative* value, because the investment is detrimental to the system as a whole.

Assuming with Oren et al. that it is the owner of the original 4 MW R_{23} TCC who strengthens line 2-3, the owner will save 1.4¢ x 4 MW = $52/hr because the 2-3 price difference goes to zero. Combined with the negative TCC

value, this produces a net loss, which should effectively prevent the detrimental expansion of the line.

IV. Conclusions

Any evaluation of investment incentives provided by transmission property rights must take into account the rules for allocating rights to the new property produced by grid modifications. Measuring the newly created property can be difficult. In fact, some "expansions" of the network can increase congestion and in effect destroy *existing* property.

TCCs, when allocated according to the feasibility rule, can, under some conditions, account for this destruction of property and penalize those responsible. This could pave the way for a market that properly accounts for the complex externalities of the electric grid. ■

Endnotes:

1. Shmuel S. Oren, Pablo T. Spiller, Pravin Varaiya and Felix Wu, *Nodal Prices and Transmission Rights: A Critical Appraisal*, ELEC. J., April, '95, at 24.

2. The concepts of transmission congestion contracts and the contract network framework were first developed in William W. Hogan, *Contract Networks for Electric Power Transmission*, 4 J REG. ECON. 211-42 (1992) ("Hogan I") and William W. Hogan, *Electric Transmission: A New Model for Old Principles*, ELEC. J., March 1993, at 18 ("Hogan II").

3. *See* letter by Kritikson, Dawson, and Ballance and response by Oren, Spiller, Wu and Varaiya in the Aug./Sept. 1995 issue of this journal.

4. Hogan I, *supra* note 2.

5. *Id.*

6. The interaction of CFDs and TCCs is examined in detail in J. Bushnell and S. Stoft, Transmission and Generation Investment in a Competitive Electricity Industry (U. of Calif. Energy Inst., PWP-030, May 1995).

7. These results are derived in J. Bushnell and S. Stoft, Electric Grid Investment Under a Contract Network Regime (U. of Calif. Energy Inst., PWP-034, Aug. 1995).

8. Following Oren et al., we use the "D.C. load flow" model and assume that there are no losses. The results, subject to a slight redefinition of TCCs, do extend to lossy networks.

9. This is just one set of new contracts that could be chosen; in fact other sets would be more valuable.

10. A less extreme case would give the same qualitative result after more difficult calculations.