MARKET POWER: A DYNAMIC DEFINITION

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Abstract

Market power refers to conditions where the providers of a service can consistently charge prices above those that would be established by a competitive market. There are many well known definitions of market power, including indices intended to quantify the degree of market concentration of energy supplies. Market power assessment within electric power markets require the consideration of the ever changing network conditions that result from congestion. This paper explores the effect of changes in network congestion conditions on one of these indices, the Herfindahl-Hirschman Index. Results indicate that congestion can lead to drastically different values of this index at various locations. Furthermore, when ownership of facilities is dispersed, this can greatly complicate the assessment of market concentration. The paper also explores several topics on strategic behavior possibilities. Keywords: Congestion management, electric power transmission, monopoly, market concentration.

1 Introduction

Market power refers to the concentration of resources in the hands of a single producer or an insufficient number of producers. One of the most common means for measuring market power is the Herfindahl-Hirschman Index (H) [1]. This index is defined as follows:

$$H = \sum_{i=1}^{N} s_i^2 \tag{1}$$

where the summation is over all N participants in the market and s refers to the market share of each. The share can be expressed in per unit (in which case the maximum value of H is 1) or in percent (in which case the maximum value of H is 10000). The latter is more common, and is used here[1].

Other measures of market concentration are possible. Two other common measures of concentration are the 4-firm and 8-firm concentration ratio (defined as the fraction of the total market held by the 4 or 8 largest firms). Yet another index is the entropy coefficient E, defined as:

$$E = \sum_{i=1}^{N} s_i \log_2 (1/s_i) \tag{2}$$

This is zero under pure monopoly and rises nonlinearly as the number of firms increases. Each market concentration index has advantages and disadvantages. A concise review of these indices can be found in [1]. It is impossible to establish a clear value below or above which market power exists for any index[2]. Many other aspects of a market not directly captured by these indices (most notably, ease of entry into a market) play heavily into the significance of specific quantitative values of an index. The greatest usefulness of these indices may be their value as relative market power indicators: a larger value of H indicates greater market concentration (and therefore the *potential* for greater market power) than a smaller value. The true measure of market power is the ratio between actual prices and the prices that would arise from true marginal cost pricing. This paper considers only market power as measured by H. For other efforts that study the effect of market power on electricity markets, refer to [3, 4, 5]. For a simulation analysis of the effect of network constraints on non-perfect markets refer to [6].

2 The Examples

The paper describes all concepts by means of examples. The first example corresponds to a a case of seven locations. Each location is assumed to be a market with one or more generating units supplying power. Table 1 illustrates the assumed size of the generating units that are supplying power, each under separate ownership. These markets can be all separate, or can be interconnected in various ways. The second example corresponds to a network situation where the suppliers are always at seven different locations from the nine demand locations. The markets in this case are defined from the perspective of the demands. The market consists of the demands at that location, along with all those suppliers capable of delivering power to that demand location.

If each location is treated as a separate market, the

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[1] Under the Cournot (quantity-setting) assumption, H has the interpretation that $n = \frac{1}{H}$ (H in per unit) is the *equivalent number of equal-sized competing firms that are participating in a given market*. Thus, a H equal to 2500 indicates that there are four equal-sized firms in active competition.

[2] However, the US Department of Justice issues and revises guidelines for mergers [2]. These guidelines rely on the use of the H to determine appropriate conditions that indicate market concentration. According to these guidelines, "the Agency divides the spectrum of market concentration as measured by the HHI into three regions that can be broadly characterized as unconcentrated (H below 1000), moderately concentrated (H between 1000 and 1800), and highly concentrated (H above 1800)."

Table 1: Generation supply markets along with sizes of suppliers and Herfindahl-Hirschman Index (H) for each market in isolation and for the total system.

Location	Suppliers	Supplier sizes (MW)	H
1	3	500 200 100	4687
2	1	500	10000
3	2	500 300	5312
4	4	100 100 100 100	2500
5	3	300 300 300	3333
6	1	100	10000
7	1	2000	10000
All	15	All of the above	1091

Table 2: H under simple two-way market separation

Market 1	H	Market 2	H
1	4688	2,3,4,5,6,7	1395
1,2	3254	3,4,5,6,7	1621
1,2,3	2018	4,5,6,7	2292
1,2,3,4	1488	5,6,7	3200
1,2,3,4,5	1038	6,7	8347
1,2,3,4,5,6	988	7	10000

H index for each generator location can be determined using equation 1 and summing over all the generators at that particular location. If, on the other hand, the entire grid is treated as a single market the same can be done using all generators. The H index at the load locations depends on which suppliers are able to compete to provide power at the given location.

Assume now that H below 2500 is sufficient to assure a competitive market[3]. In isolation, only the market at location 4 is marginally competitive. The markets at locations 2, 6 and 7 are pure monopolies. The market, when operated as a single system-wide market with free-flowing trades, is well below the threshold for monopoly conditions.

The above production levels assume supply exactly matches demand at all times. The numbers used in the computation generally represent actual production levels and actual market shares. This, however, may *overstate* the monopoly condition, by not taking into consideration possible new entrants into each market.

Instead of using actual production numbers in the estimation of H, we can use the capacity of all available units in a region. However, computing H considering capacity may *understate* the potential threat of market power concentration in a region. This is because it is not reasonable to assume that all units are able or capable to enter a given market in a timely fashion. Only units that are "close to operability" can be assumed to participate in a given market at any one time.

[3]This value is higher than the recommended value from the Department of Justice. However, it is the relative effects on the H index that are of greater interest in this paper.

Table 3: Market power under the assumption that market 2 can sell power to market 1 but not vice-versa

Market 1	H	Market 2	H
1,2,3,4,5,6,7	1091	2,3,4,5,6,7	1395
1,2,3,4,5,6,7	1091	3,4,5,6,7	1621
1,2,3,4,5,6,7	1091	4,5,6,7	2292
1,2,3,4,5,6,7	1091	5,6,7	3200
1,2,3,4,5,6,7	1091	6,7	8347
1,2,3,4,5,6,7	1091	7	10000

This paper does not attempt to settle the above questions. Instead, it assumes that, whatever numbers are used, they are used consistently. The main issues addressed in this paper are (1) the effect of congestion on market concentration, and (2) the effect of network flows.

3 H under radial congestion conditions

Under the single market assumption, H is 1091. Congestion has the effect of separating markets. Assume, for example, that the market is cleanly separated into one market consisting of locations 1 to 4, and a second market consisting of locations 5 to 7. Congestion that results in a clean separation between two markets leads to different conditions for each region of the system. Table 2 illustrates H for various separation possibilities (many other separation possibilities exist, including separation into multiple markets). Market separation leads, under most of the conditions illustrated, to market concentration within one or the other market. In the example, only the case of separation into (1,2,3) and (4,5,6,7) leads to a case where neither market sees excessive market concentration.

Congestion in electric power systems is, however, unidirectional. This means that it is possible for suppliers from the downstream location to supply power to the upstream location, but not vice-versa. If this is taken into consideration, different results are obtained. Assume that market 2 can sell to market 1, but that the opposite is not true. Under this assumption, the market power condition for market 2 is based only on those participants located within market 2, while the index for market 1 is based on those participants located at either end of the congestion (all participants in this case). The results are summarized in table 3. Under this unidirectional assumption, market power never develops within market 1, but develops within market 2 when less than 3 suppliers are able to participate in that market.

4 H under network congestion conditions

The existence of a network makes congestion far more subtle. As a first attempt to a better understanding of congestion in networks, we use the notion of "contributions to flows" as described in [7]. The notion is that the delivery of power to any single location within the network can take place from any one generator at any time. However, this delivery will result in incremental (sometimes decremental) flows in most lines within the grid. Consider the 16-node network illustrated in Figure 1. The delivery of power to a specific location from each and every one of the 7 generation supply markets can be easily established using sensitivity flow information. Figure 2 illustrates the flows that can be attributed to the delivery of power to the consumers at location 16 from the suppliers located at location 1, and figure 3 illustrates the flows that can be attributed to the delivery of power to the consumers at the same

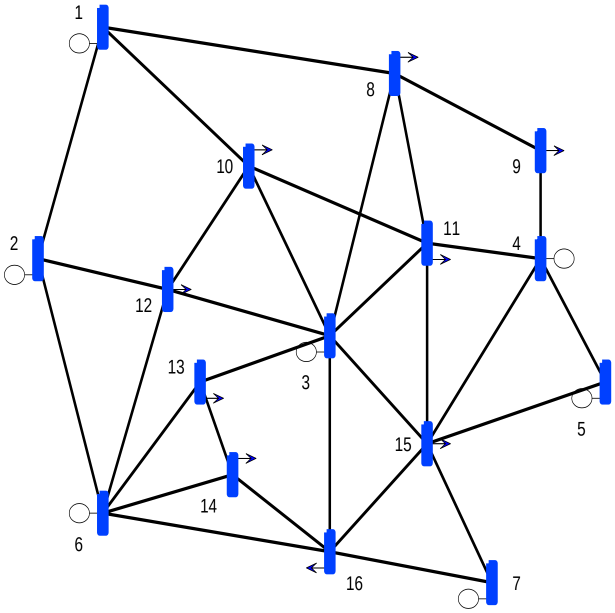

Fig. 1*: Diagram of the network illustrating location of supply and demand markets.*

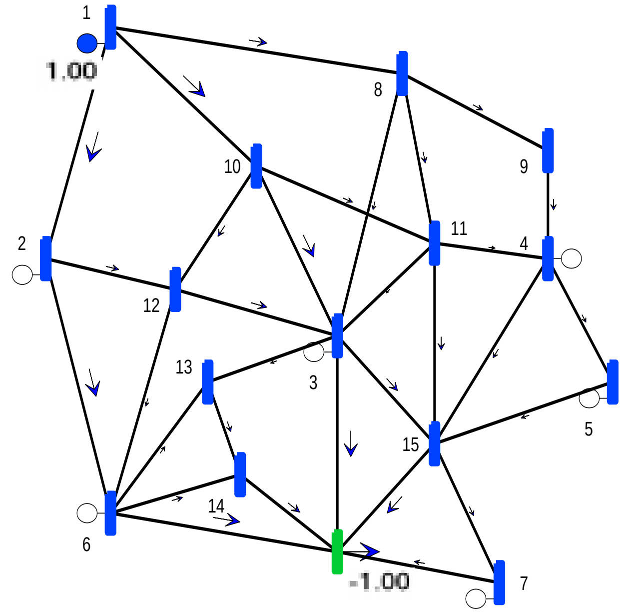

Fig. 2*: Flow contributions for delivery of 1 MW power to market 16 from suppliers at 1.*

location 16, but this time from producers at location 6. The pattern of flows is quite different. It can be readily seen that the effects of flows can be far-reaching. It can also be observed that location of both suppliers and consumers matters. However, as long as there is no congestion (and as long as losses can be neglected) anyone can supply power from any market to any demand. Thus, the computation of market power indices is exactly as before.

Assume now that congestion occurs as indicated in figure 4, and that the *direction of congestion* is in the direction indicated by the large in-line arrow. That is, any transaction that tends to produce a flow in the direction indicated by the arrow is not a permissible transaction. The result is that only *certain* locations are able to deliver power to each particular demand location in the grid when operating as a bilateral trade. For the example at hand, location 16 can only be supplied by the producers at location 6. Any other location produces a positive flow on the line from 2 to 6.

For any specific system congestion condition, it is possible to determine precisely which supply markets can deliver power to each demand location and which suppliers are prevented from doing so. Table 4 illustrates, for each demand location, which generators are able to participate in sales into that market under the assumption that the path from 2 to 6 is congested. This permits the determination of a different H index at each customer location.

Even congestion at a remote location can lead to similar problems in principle. Table 5 illustrates the same results but for congestion occurring in line 8–11. This table illustrates a further important point: two locations (11 and 15) *cannot* be served by any bilateral trade if line 8–11 is congested. What is the solution to this apparent dilemma? One of the following:

- A multilateral trade is arranged [8] (see also the next section).
- The demand at that location is price rationed or a congestion price is added to the intended transaction(s)[4].
- The demand at that location is quantity rationed by an operator (or some energy trade(s) disallowed or cancelled).
- Ignore the effects of the transaction on the congested flow if the effect is below some arbitrary threshold.

Table 4: Supply locations able to deliver power to demand locations under bilateral agreements when the path from 2 to 6 is congested. The H indices for each location are also illustrated.

Demand location	Feasible supply locations	H
8	3 4 5 6 7	1621
9	3 4 5 6 7	1621
10	3 4 5 6 7	1621
11	3 4 5 6 7	1621
12	3 4 5 6 7	1621
13	6	10000
14	6	10000
15	6 7	8347
16	6	10000

5 H under multilateral trades and congestion

Suppliers can "circumvent" flow limitations if they have ownership at different locations. To illustrate this important point, consider the same system as above, but now consider that there are only 5 distinct owners, with ownership shares as illustrated in table 6. As before, consider that only those locations that do not

[4]Who gets the surplus from price rationing depends on contractual and institutional arrangements beyond the scope of this paper. See also the section on Strategic Behavior.

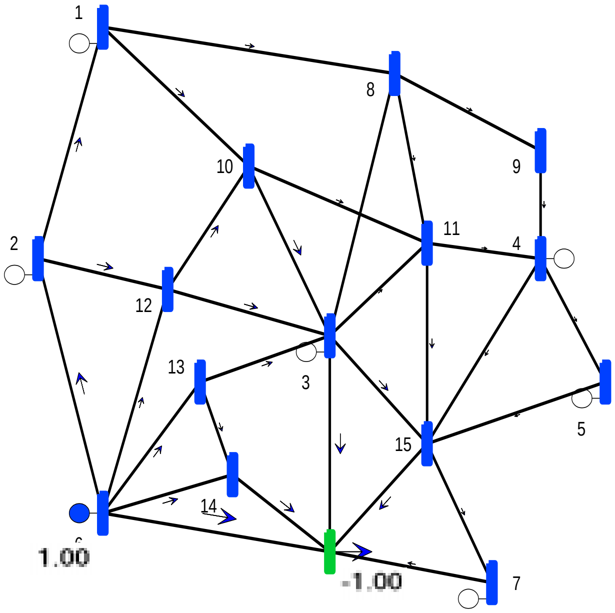

Fig. 3*: Flow contributions for delivery of 1 MW of power to market 16 from suppliers at 6.*

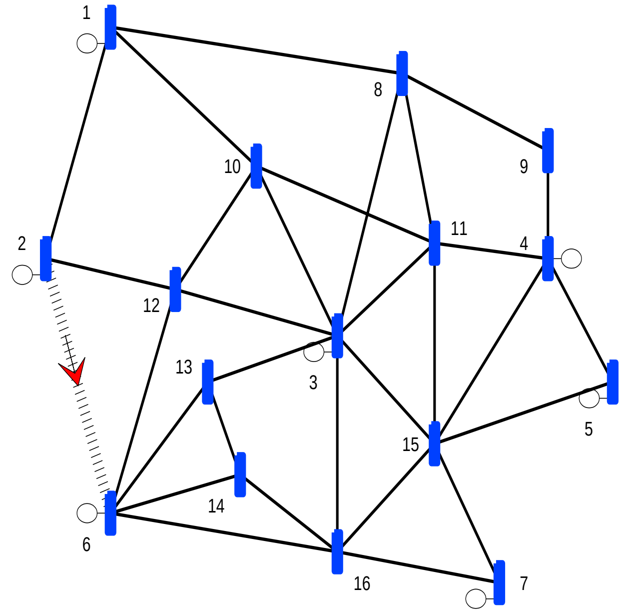

Fig. 4*: Congestion in line 2-6. Flows in the direction shown cannot be tolerated.*

increase the congested flow are able to participate in a given market. If we restrict the trading to purely bilateral trades, we obtain the same results as table 4 and table 5. However, power delivery is in fact possible by means of a *multilateral* trade under congestion conditions[5]. Thus, suppliers that *have* multiple locations can now participate in trading in markets that would be foreclosed to them without this option. Thus, although the number of participating players has been greatly reduced, the resulting H at every node is actually lower as a result of the greater possibility for participation. The question remains, however, as to what numbers to use in the calculation. By means of a multilateral trade a participant can now participate in a trade where he/she was not able to participate before. In reality, however, only a fraction of the total power can be funneled from any location. The remainder has to come from some other location. Since we are presently concerned only with the ability to participate, we continue to use the total power supplied to *any* location by each owner when computing H. Using this method (which we expect underestimates[6] the effective market concentration as measured by H), we obtain the results in tables 7 and 8 for the cases of congestion in lines 2–6 and 8–11.

6 Strategic Behavior

H measures the potential for market power. This section explores various ways in which market power can be created or exploited. Of particular interest are the possibilities for strategic behavior that result from dispersed ownership. For example, there are situations where a legitimate transaction by a network participant leading to a more competitive prices at one location can have the indirect effect of increasing the market power for the same owner in a different and seemingly unrelated location.

Consider the possible behavior of owner 1. Assume location 1 is a highly competitive location, with low energy prices. Behavior on the part of owner 1 that tends to increase the flow on line 2–6 (such as an increase on supplies from unit 1) can readily lead to congestion on line 2–6. Once this happens (particularly if this happened under the guise of delivering a maximum amount of inexpensive power) other potential competitors (such as anyone located at locations 2, 3, 4, 5 or 7) are unable to deliver power into the market at location 16. As a result, owner 1 now enjoys much greater market concentration, since the only feasible competitors are those located at location 6.

To formalize these concerns, we use the flow sensitivity matrix S. This matrix gives the impact on any flow (rows of S) as a result of any injection (columns of S), relative to an implicit (arbitrary) "slack" location[7]. The change on the vector f of all flows as a result of a bipartite generation shift of 1 MW to location i from location j is given from:

$$\Delta f = S_{*i} - S_{*j} \tag{3}$$

where S_{*i} represents the i^{th} column of S.

For the case at hand, imagine that owner 1 has market power within location 6 (and thus could, in principle, price according to monopoly strategies). To keep the analysis specific, assume the following:

[5] As [9] indicated, one congested line requires a minimum of two actively participating suppliers, two congested lines requires a minimum of three participating suppliers and so on.

[6] The option for expanded potential trades afforded by multilateral transactions is likely to have the effect of making markets more contestable. Thus, the *possibility* of multilateral trades should have the effect of reducing the effective market concentration.

[7] The choice of some slack location is, however, essential to maintain the power balance requirement.

Table 5: Supply locations able to deliver power to demand locations under bilateral agreements when the path from 8 to 11 is congested. H for each location is also illustrated.

Demand location	Feasible supply locations	H
8	1 2 3 4 5 6 7	1091
9	1 2 3 4 5 6 7	1091
10	3 7	4136
11		*
12	3 7	4136
13	3 7	4136
14	3 7	4136
15		*
16	3 7	4136

(*) The markets at locations 11 and 15 cannot be supplied by any single supplier without violating the flow restriction. See text.

Table 6: Generator ownership table.

	Owner (MW)				
Location	1	2	3	4	5
1	500	200	100		
2	500				
3	300	500			
4	100	100	100		100
5		300	300	300	
6	100				
7				2000	

- Line 2–6 is potentially congested. It is 200 MW away from congestion, and owner 1 realizes this is the case.
- Owner 1 owns all the generation resources at location 6 (100 MW in our example).
- The price of power at location 1 under competitive conditions has been estimated at \$20 per MWh. However, it is known that monopoly pricing could lead to prices around \$30.
- The sensitivity of the flow on line 2–6 to a shift in generation from location 4 to location 1 is 0.8. That is, for every MW that owner 1 shifts from location 5 to location 1, there is an increase of 0.8 MW in the potentially congested flow. Thus, a shift of 250 MW from location 1 to location 4 will result in congestion.
- Assume it costs owner 1 an additional \$1 per MWh to produce power at location 4 than at location 1. Thus, to "produce" congestion it would cost owner \$250 per hour.
- Owner 1 has additional resources at location 6 which can be brought on line at a cost above \$20 per MWh but well below the monopoly price (say, at \$21 per MWh).

Table 7: H per location for separately owned markets when congestion in line 2–6 develops.

Location	Owners	H
8	1,2,3,4,5	2978
9	1,2,3,4,5	2978
10	1,2,3,4,5	2978
11	1,2,3,4,5	2978
12	1,2,3,4,5	2978
13	1,2,3	3861
14	1,2,3	3861
15	1,2,3,4	3086
16	1,2,3	3861

Table 8: H per location for separately owned markets when congestion in line 8–11 develops.

Location	Owners	H
8	1,2,3,4,5	2978
9	1,2,3,4,5	2978
10	1,2,4	3644
11		*
12	1,2,4	3644
13	1,2,4	3644
14	1,2,4	3644
15		*
16	1,2,4	3644

(*) The inability to deliver power to these locations under congestion conditions has *not* been resolved by the multilateral trading possibility.

Under these conditions, if congestion develops owner 1 is the only one capable of supplying power to location 16. Thus, owner 1 could do so at the monopoly price (or at least at a price above the fully competitive price). In the example at hand and under the assumptions given, the initial cost to owner 1 of the strategic behavior leading to congestion is \$250. However, for every MW of additional demand at location 16, the additional revenues that can be derived by owner 1 assuming full monopoly pricing of the additional resources is \$9 per MWh. Thus, it would only take an additional demand of about 30 MW at location 16 for owner 1 to recover the cost of the strategic behavior. In addition to this, the spot price for *all* power delivered to location 16 would rise, leading to a windfall benefit to all participants in this market, not only to owner 1.

The situation becomes more subtle when the price to produce power at location 1 is lower than the price to produce power from location 4. In this case, it can be argued that owner 1 is not necessarily engaging in strategic behavior when a decision is made to lead to conditions that result in congestion, and indirectly lead to temporary localized market concentration.

It is possible to determine a threshold above which the incentive is there for participants to engage in behavior leading to market concentration by strategic behavior. For an analysis of this idea, refer to [3].

The determination of the exact potential effect of market concentration on prices requires as a precondition that accurate an appropriate methods for network marginal cost pricing be used as the basis for pricing. Such calculations have been known for some time [10, 11] and recently reviewed and their use in practical systems demonstrated in [12].

7 Further considerations

Market concentration in electric power grids is not likely to be a simple, sustained condition but rather a fluid, changing condition. Thus, in assessing market concentration, it is perhaps more appropriate to talk about the *probability* of market concentration. In this sense, the use and definition of an effective mean value for H (or at least a weighted value that takes into consideration the various probabilities of market concentration developing) needs to be performed. Without this analysis, it is possible for owners of supply resource to play subtle games depending on the anticipated probabilities of congestion. The matter warrants further discussion and consideration.

Another aspect of market concentration is market concentration that arises as a result of system limitations other than simple flow limits. An example of this is market concentration arising as a result of reactive power. Reactive power is a commodity essential to maintaining voltages within the system. The ability to transmit power in many cases is directly linked to the availability of reactive power. Specifically, the events of the summer of 1996 in the Western US have been linked ultimately to insufficiency of reactive power resources along the transmission line. This issue also deserves further consideration.

Another consideration is the interaction between market concentration and transmission congestion contracts. In addition to the already understood issues relating to transmission congestion contracts and their relationship to spot prices (including the opportunities for strategic behavior in terms of the congestion contracts themselves), the inclusion of market concentration considerations in the analysis of the interaction between transmission prices, spot prices and monopoly pricing possibilities deserves further consideration [13].

8 Conclusions

Market power is a fluid concept when dealing with power networks. Congestion can have a profound effect on measures of market concentration such as the Herfindahl-Hirschman Index H. Congestion is not bidirectional, the effect of market concentration is different at different locations. Some locations see no impact, while others are adversely affected. Market power in networks is subtle and hard to quantify. In general, the possibility of multilateral trades reduces the effect of market concentration by making more suppliers available for any given transaction (but reduces the overall number of participants in the market). The net effect on a grid of permitting dispersed ownerships (and thus enabling multilateral trades) needs to be carefully examined in a case-by-case manner.

Dispersed ownership opens up the possibility for subtle strategic behavior. Dispersed ownership of generating facilities has great value as an instrument for flow control capable of creating new trading opportunities that are foreclosed to those with single or few points of supply. The ability to manage dispersed demand is just as valuable in this context as the ability to manage dispersed supplies. Thus, demand management programs with geographically dispersed characteristics can be far more valuable than demand management programs that do not have a locational capability. For further information on the design of programs that have these characteristics, refer to [12].

REFERENCES

[1] F. M. Scherer. *Industrial Market Structure and Economic Performance*. Rand McNally College Publishing Company, 1980.

[2] Justice Department and Federal Trade Commission. Horizontal merger guidelines. Revision issued April 8, 1997, originally issued April, 1992.

[3] W. W. Hogan. A market power model with strategic interaction in electricity networks. *The Energy Journal*, 18(4):107–141, 1997.

[4] S. S. Oren. Economic inefficiency of passive transmission rights in congested electricity systems with competitive generation. *The Energy Journal*, 18(1):63–83, 1997.

[5] L. J. Perl. Measuring market power in electric generation. *Antitrust Law Journal*, 64:311–321, 1996.

[6] Z. Younes and M. Ilic. Transmission system constraints in non-perfect electricity markets. 1989.

[7] D. Kirschen, R. Allan, and G. Strbac. Contributions of individual generators to loads and flows. *IEEE Transactions on Power Systems*, 1996.

[8] F. L. Alvarado, R. R. Rajaraman, F. Schulz, and V. Niemeyer. Location based trading and risk management. In *Pricing Energy in a Competitive Market*, Renaissance Mayflower Hotel, Washington, DC, June 17–19 1998. EPRI.

[9] H. Glavitsch and F. L. Alvarado. Management of multiple congested conditions in unbundled operation of a power system. *IEEE Transactions on Power Systems*, 1997. (To appear.) Presented at the PICA Conference, Columbus, Ohio, May 1997.

[10] F. C. Schweppe, M. C. Caramanis, R. D Tabors, and R. E. Bohn. *Spot Pricing of Electricity*. Kluwer Academic, Boston, 1987.

[11] R. E. Bohn, M. C. Caramanis, and F. C. Schweppe. Optimal pricing in electrical networks over space and time. *Rand Journal of Economics*, 15(3):360–376, 1984.

[12] M. Fahrioglu and F. L. Alvarado. The design of optimal demand management programs. In C. Vournas, editor, *Bulk Power System Dynamics and Control*, 1998.

[13] T.O.Nasser. Transmission congestion contracts and strategic behavior in generation. *The Electricity Journal*, 11(4):32–44, May 1998.