Competitive Power Market Analysis - Evaluation of Market Power due to Congestion Effects on Transmission System

Manuel João D. Gonçalves[1], and Zita A. Vale[1]

[1] Polytechnic Institute of Porto (IPP)/Institute of Engineering (ISEP)/Departement of Electrical Engineering (DEE)
Rua Dr. António Bernardino de Almeida - 4200-072 Porto (Portugal)
phone:+351 22 8340500, fax:+351 22 8321159,
e-mail: mjg@dee.isep.ipp.pt, zav@dee.isep.ipp.pt

Abstract. The new electrical market deregulation has given rise to competition with the goal of price fall and technological innovation in the sector.
In the last few years a great deal of attention is given to the possibility of a group of producers (agents) exercise market power by means of congestion effects.
Market power due to the possibility of a small number of generators act in a combined way is presented. The paper describes a algorithm used to detect, quantify and evaluate the impact of these kind of strategic actions on market concentration. The results obtained from the study on two distinct example networks shows that this kind of actions can affect strongly market share and must be predict by the ISO.

Key words

Electricity market, market concentration, market power, PTDF (Power Transfer Distribution Factors), SIC (System Interchange Capacity), congestion.

1. Introduction

The electrical power market is under a rapid changing process in the entire world. Nowadays the principal electrical energy markets have a philosophy of high competitive market in which every agent can sell energy to other agents. The main goal of this kind of structure is to force the decrease of product price (electric energy) and the increment of innovation and consolidation of reliability and quality standards in electrical energy power systems [1], [2], [3].
In the new competitive electricity market environment, the transmission system takes a important role. One of the ISO (Independent System Operator) key functions is congestion management.
Congestion occurs whenever the transmission network is unable to accommodate all the desired transactions due to the violation of one or more constrains for the resulting state under both the base case and a set of specific contingencies. The open access transmission regime results in the more intensive use of the transmission system, witch, in turn, leads to more frequent congestion situations. The task of congestion management requires the ISO to identify and relieve such situations throughout the deployment of various physical or financial mechanisms.
For different power market structures, the approaches to managing congestion may vary.
The electricity market behaves more like an oligopoly than an ideal market due to its special features such as, a limited number of producers, large investment size, transmission constrains and natural or artificial congestion and transmission losses. Congestion, witch could isolate consumers from effective reach of some agents, and transmission losses witch discourage consumers from purchasing from distant suppliers.
When one agent owns a share of market it has what is called market power and can start to act as a price-maker rather than a price-taker. Special attention must be given to the possibility of market power rise. The market power of an agent is a very important factor because it can change in a strong way the power market definition itself [4].
Market power is harmful to competition and it is necessary to identify the potential for its abuse. It depends on the intrinsic characteristics of the electric power system. The transmission system is still an important part of the power system and directly depends from the ISO. Because transmission limits can be an important source of market power, many models of strategic interaction on networks have been developed [5].
There are various definitions of market power. In general, market power is referred to as the ability of a market participant to profitably maintain prices above a competitive level for a significant period of time. A agent has market power if it can influence the market equilibrium point. Where there is a price maker, there is some degree of market power. Market power may range from a full market to a local market. Market efficiency is obtained through competition. Market power is undesirable as it is a symptom of an uncompetitive industry and can lower economic efficiency.
While the manifestation of market power abuse is usually associated with higher price above cost, it can also be lower quality of products or services compared to what would be found in a more competitive environment. Thus, it is not possible to measure market power only by

calculating the percent price rise above cost. It is important to retain that market power it is not only limited to sellers. Buyers can also have market power. For example large customers have more ability to affect pricing than smaller ones.
In the paper, we propose some studies to make a quick and precise evaluation of market power and market concentration due to strategic coalition, according to a specific image of the power market.

2. Market Power Evaluation

A. Sources of Market Power

Market power can appear in two main forms. The market dominance and transmission constrains. The market dominance is the power market of a agent that, in face of his dimension, can affect in a strong way the price. An example is the England and Wales pool where a highly concentrated market have allowed two dominant sellers, National Power and Power Gen.
Transmission constrains is the case more closely analyzed in this paper and reflects the existence of transmission congestion due to suppliers actions. A supplier can profit from increasing, rather than decreasing, production in strategic points in the network to create line congestion, limiting the access of competitors to a given market. In this way, a local submarket will be created and the agent or agents will be in position of monopoly.
Congestion can, in fact, create conditions of market inefficiency in a short-term scenario. It is said that transmission systems introduces a degree of inefficiency into electricity markets [6].

B. Market Power in Electricity Markets

Great price increase is an intuitive manifestation of market power, such as drastic price increase during some periods are also the result of market power abuse.
In California wholesale electricity market during June-November 1998, the actual price of electricity was 22% above the competitive level [7].
For example on November 25, 1997, in the National Electricity Market of Australia the electricity price reached so high values that it is possible to conclude that market power abuse exists in the New England market (NEPOOL) with more incidence in the peak load period [8].

C. Market Power Analysis

Price increase above competitive levels is a manifestation of power market.
Many factors should be taken in account when evaluating the competitiveness of an electricity market. It includes:

1) Market share
2) Market concentration
3) Elasticity of demand
4) The amount and distribution of excess capacity
5) Process of establishing prices
6) Transmission system limitations.

The evaluation of the existence of market power own by one or more combined agents in Electric Power Market is done attending to the following issues:

1) Identification of relevant products and services
2) Identification of the geographical situation of the market
3) Analysis of market share and market concentration
4) Estimation of pricing behaviour through simulation analysis
5) Oligopoly equilibrium analysis.

In the present paper only short-term scenario study is done.

D. Market Concentration

Market power can be evaluated based in the perfectly competitive equilibrium price. In general the first step to evaluate the competitiveness of market structure is to analyze market share of suppliers. After assigning market shares to each supplier it is easy to reflect these shares in an index of market concentration. Knowing the degree of concentration provides useful information about where on the competitive spectrum the market lies and what other factors will have to be considered to enable a effective and easy way to find the existence of market power [9]. The most used process is to calculate the so-called HHI index (Herfindahl-Hirschman Index) [10].
The HHI is calculated for a precise market and traduces the accessibility distribution of the participants to the market.
In a N participant Network the HHI index is evaluated as in (1).

$$HHI = \sum_{i=1}^{N} (p_i)^2 \tag{1}$$

p_i - Percentage of market owned by each participant.

For example, for three suppliers with shares of 20, 35 and 45 percent the HHI would equal 3650 ($20^2+35^2+45^2$) in contrast with HHI=3333,3 corresponding to equal share.
In the case of one generator having the totality of the Market Power the HHI calculation assumes its maximum value of 10000 (100^2+0+0+0).
The HHI approaches 0 when there are a large number of very small suppliers and equals 10000 when there is just one. HHI gives proportionally greater weight to the market share of the large suppliers and takes in account all suppliers in the market [9].The HHI method has played a prominent role in the FERCs (Federal Energy Regulatory Commission) decision in respect of electricity suppliers merging.
The HHI method has the advantage of specify with the drawback that it has no supporting theory and it is intended as a rule of thumb. This method is used because it:

1) Gives proportionately greater weight to the market share of the larger suppliers
2) Takes into account of all suppliers in the market.

3. Power Transfer Distribution Factor

The evaluation of the situation regarding power market can be done using the power transfer distribution factor (PTDF) associated to a specific power transfer between one selling point and one buying point in the network. This factor can express, in a linear approximation, the way a given power transfer can affect each one of the lines in the network. The calculation of PTDF is used by the ISO to validate transactions according to the physical limits of the network lines [11], [12]. PTDF is a factor associated to a given transaction in a specific direction (selling node - buying node) and calculated for each line [13]. As an example of the calculation let us consider the nine bus network presented in Fig. 1.

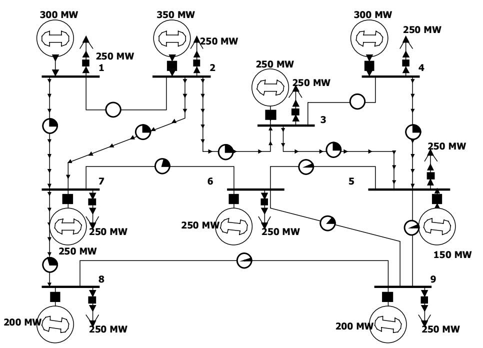

Fig. 1. Nine bus example network

In this network :

1) Each node has a generator with limiting power generation of 500 MW and a load of 250 MW
2) Each node is an agent that can by and sell electric power energy in the market
3) Each transmission line has a power limit of 200 MW and an impedance of j0.1 p.u. (active power losses in the network are neglected).

For a specific transaction, the PTDF calculation can be done. If node 1 is selling to node 9 100 MW the PTDF for each line can be calculated as in (2).

$$P_{ij1} = P_{ij} + PTDF(i,j,h,l) \cdot P_{hl} \qquad (2)$$

P_{ij1} Active power in line ij after transaction
P_{ij} Active power in line ij before the transaction
h,l Transaction direction (Selling node to Buying node)
P_{hl} Power transaction in MW.

It is possible, for a specific transaction, to have a clear image of power flows in the all the lines in the network. Fig. 2 presents the calculated PTDF for each line (1-9 power transaction percentage flowing in each line).

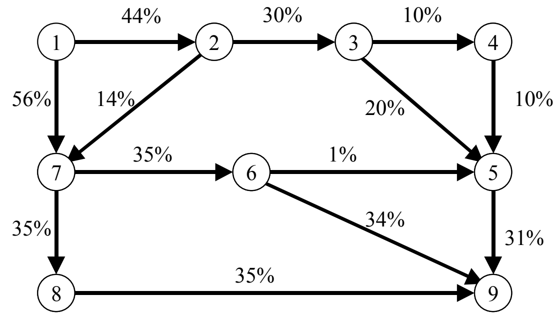

Fig. 2. PTDF for 1-9 transaction

Combining the PTDF information with the line power transmission capacity it is possible to calculate the maximum transaction that a pair of participants can establish and identify the limiting line.
The maximum transaction value in a k direction (selling node - buying node) can be determined by (3).

$$P_{k\,\text{máx}} = min\left[\frac{P_{ij\,\text{máx}} - P_{ij}}{PTDF(i,j,k)}\right] \qquad (3)$$

P_{ij1} Active power in line ij after transaction
$P_{kmáx}$ Maximum active power in k direction
$P_{ijmáx}$ Line power transmission capacity of line ij
P_{ij} Active power in line ij before the transaction k.

Table I present the maximum transaction allowed and the limiting line for different transaction with node 9 as buyer.

TABLE I. - Transmission system limitation

TRANSACION	MÀX (MW)	LIMITING LINE
1---9	266	1---7
2---9	374	2---7
3---9	328	3---5
4---9	253	4---5
5---9	323	5---9
6---9	319	6---9
7---9	374	7---8
8---9	278	8---9

The use of PTDF is decisive to rapidly obtain and locate which elements are limiting a transaction [14].
Actually, in United States, NERC (North American Reliability Council) publishes regularly the PTDF for each line for each transaction for a given instant. The maximum allowed value for PTDF is 5% to validate a transaction.

4. Forced Transmission Line Congestion

It is possible that some agents combine actions to rise their joint market share, affecting in a strong way the concentration index for a given market. In fact, is possible to reconfigure the generations of each agent in order to affect the power flow in a specific line creating a forced transmission line congestion. It is possible to see, in the network of Fig. 1, for the proposed dispatch that if

agents 7 and 8 join efforts and alter their individual productions (maintaining their total production) it is possible to affect in a strong way the active power flow in line 7-8 leading to a artificial congestion situation.
After altering their production generator 7 must produce 450 MW and generator 8 0 MW (corresponding to a global generation of 450 MW). The line 7-8 transmission active power limit is reached and as a consequence the HHI index show a situation of rise in market concentration leading to rise in market power. Fig. 3 shows this situation and the impact of that coalition.

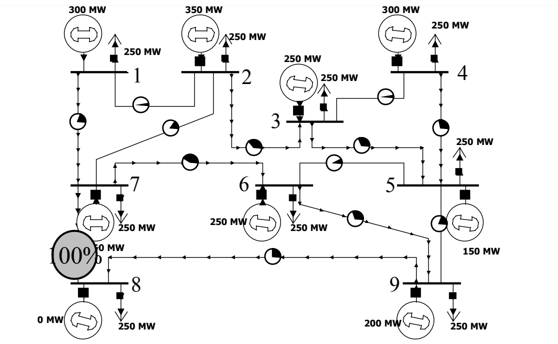

Fig. 3. Impact of 7-8 coalition

In the proposed study only coalition of two agents is assumed. The calculation method proposed is based on the Power World Simulator (for Power Flow calculations and visualisations) combined with MatLab. To obtain the maximum congestion effort, for the two agents, it is necessary to calculate the sensibility factors that give the relation between the increase of power in each line with the increase on power production in a specific generator. After obtaining the active power flow in each line *Pij* we calculate the sensibility factors (SENS), as in (4).

$$SENS(h,l,i) = \frac{\Delta P_{hl}}{\Delta P_i} \tag{4}$$

SENS (h,l,I) Sensibility factor for line *hl* due to generator *i*. (percentage of injected power that flows in line *h-l*).
ΔP_{hl} Variation of active power flow in line *hl*
ΔP_i Generation variation in node *i*.

$$\Delta P_{hl} = \text{máx}\left[SENS(h,l,i)\cdot \Delta P_i + SENS(h,l,j)\cdot \Delta P_j\right] \tag{5}$$
$$Sub.\,to$$
$$\begin{cases} \sum_{k=i,j} \Delta P_{Gk} = 0 \\ P_{Gkmin} \le \Delta P_{Gk} \le P_{Gk\,\text{máx}} \end{cases}$$

P_{hl} Active power in line *hl*
P_i Active power generated by *i*
P_j Active power generated by *j*
P_{Gkmin} Minimum generation in *k*
$P_{Gkmáx}$ Máximum generation in *k*

After calculating this factor for each line, it is possible to maximise by (5) the impact of generation reconfiguration in the transmission system.
After the calculation for all lines in the network it is possible to evaluate the new power transmission limit capacity for each line due to congestion [15], [16], [17]. So it is possible to recalculate de new line limits when in presence of forced line congestions resulting from two agents coalition.
In a market where an ISO controls the viability of each contract this kind of combined strategy may stay not detected. The impact of this strategic coalitions is strongly dependent of the load level.

5. Proposed Market Evaluation

The participants of an energy market can behave in two distinct ways. For instance one group will try to maximize their access to market, that is, the ability to sell the generated energy to a consumer or group of consumers (maximizers). The second group can try to minimize the access of the other to a specific market, with congesting actions, decreasing the transmission capability of some lines (minimizers) [18].
This kind of problem can be studied with Games Theory where a group of agents with distinct goals and abilities interact in well defined scenario with well defined rules. Another way to solve this problem is to use the SIC parameter (Simultaneous Interchange Capacity). This parameter traduces the maximum accessibility that a specific agent has to some market.
The SIC parameter can give a relative information of how each participant can access a market. Clearly this parameter reflects the different conditions that are defined in the network (generation, load, node voltages, power flow in each line, topology,...) and is strongly dependent to congestion situations that can appear on the transmission system. The SIC value is the maximum exported power from one selling node to one buying node considering all the participants with equal opportunities. In the present study the new line power capacity due to forced congestion are taken into account.
The upper and lower limit variation of active power (both ways) for each line after the congestion effect is calculated regarding the initial power flow in the line as in (6).

$$\begin{aligned} \Delta P_{hl} &\le \left(S_{\text{máx}} - \Delta P_{congestion}\right) - S_{hl0} \\ \Delta P_{hl} &\ge -\left(S_{\text{máx}} + \Delta P_{congestion}\right) - S_{hl0} \end{aligned} \tag{6}$$

ΔP_{hl} Variation of active power flow in line *hl*
$S_{máx}$ Maximum apparent power flow limit
$\Delta P_{congestion}$ Variation due to forced congestion
S_{hl0} Power flow before congestion actions.

In the 9 bus case study proposed (Fig. 1) the defined market is the ability to sell power to agent 9. In the initial image of the network the generator in 9 produces 200 MW. So the maximum import of this agent (maximum export from the others) will be exactly 200 MW, that will correspond to a no generation situation.

The SIC calculation is done as in (7) solving a linear programming problem where the optimised function is the export from all nodes to a specific buying node.

$$EXP = \text{máx}\left[\sum_{k=1\neq 9}^{N} \Delta P_{Gk}\right] \tag{7}$$

Sub.to

$$\begin{cases} \sum_{k=1}^{N} \Delta P_{Gk} = 0 \\ \sum_{k=1\neq 9}^{N} \left(PTDF(h,l,i,j)\right) \leq \left(S_{\text{máx}} - S_{hl}\right) \\ \sum_{k=1\neq 9}^{N} \left(PTDF(h,l,i,j)\right) \geq -\left(S_{\text{máx}} + S_{hl}\right) \\ \Delta P_{Gk} \geq 0 \end{cases}$$

ΔP_{Gk} Variation of generation in each k node
hl Line *hl*
ij Selling - buying nodes.

If this problem is solved without any kind of congestion effect the ability of each node to sell power to node 9 will be equal. So the solution for this problem, in a ideal situation, would be the represented in Table II.

TABLE II. - SIC values for no-congestion situation

Selling Agent	Export to node 9
1	25
2	25
3	25
4	25
4	25
6	25
7	25
8	25

The starting point for the used linear programming algorithm is the solution that corresponds to equal opportunity for each agent.
The solution obtained from this kind of approach can be considered pessimistic because the coalition actions taken into account regarding the forced congestion actions are maximised.
Considering the congestion effects the algorithm proposed can be described in the following steps:

1) Consider all the possible coalitions of two agents and calculate the reconfiguration of generations in order to maximise forced congestion impact in all line transmission capacity.
2) For each coalition calculate the new transmission capacity limit for each line.
3) Make SIC calculations with the new line limits.
4) Select the coalitions that affect the accessibility to the market for other agents
5) Calculate the HHI for each detected critical situation

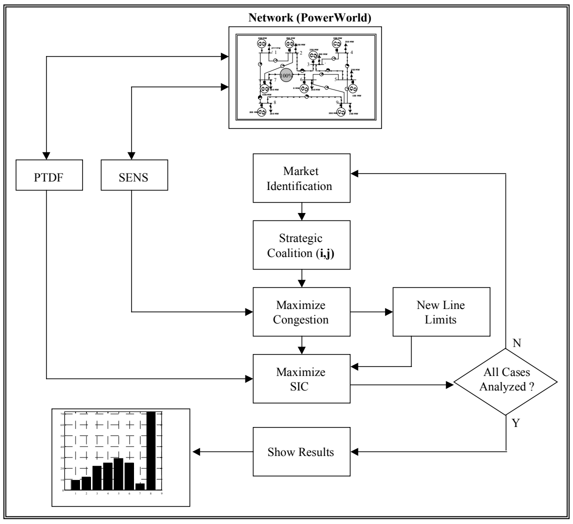

Fig. 3. Software architecture

Fig. 3 shows the proposed algorithm.
In the proposed example some critical coalitions have been detected. Fig. 4 presents the maximum export for each agent to agent 9 under strategic coalition of agents 7 and 8 [19].

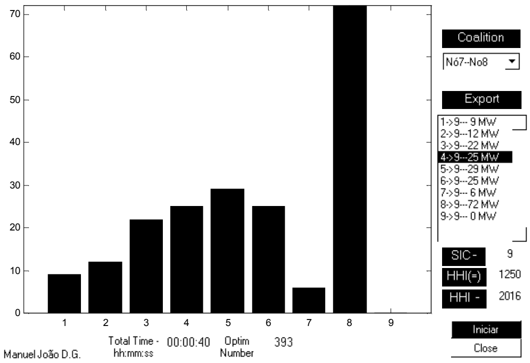

Fig. 4. SIC results for 7 and 8 coalition

Another study was done involving a larger example network. The 15 bus example network is represented in Fig. 5.

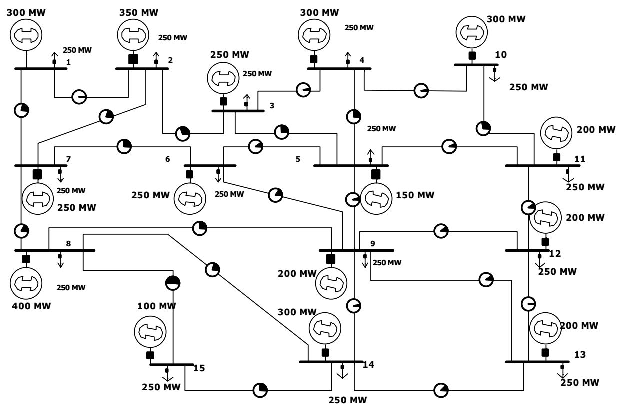

Fig. 5. 15 bus example network

For this network:

1) Each node has a generator with limiting power generation of 500 MW and a load of 250 MW
2) Each node is an agent that can by and sell electric power energy in the market
3) Each transmission line has a power limit of 200 MW and an impedance of j0.1 p.u. (active power losses in the network are neglected)
4) Electric market considered was export to node 9.

The proposed method was applied to the new example network considering all the possible coalitions between two agents. Some critical coalitions where detected and the HHI index was calculated for each of them. Table III reflects the HHI for each critical strategic coalition detected. The market considered was the ability of each node to sell power to node 9. So the HHI for equal opportunity of all the 14 nodes was HHI=714.

TABLE III. - 15 bus SIC values for detected critical coalitions

Coalition	HHI
1<>6	719
2<>15	913
4<>15	716
6<>7	962
7<>8	838
8<>15	815
10<>11	770
10<>15	719
14<>15	1979

The results where obtained after detection of coalitions where the SIC deviates from the value corresponding to no limitations of export for al the nodes. Fig. 6 shows the information reported from the application after 15 bus network analyses. If all the agents share in equal part the market the SIC result would be 200/14 MW for each agent. It is possible to see the deformation in SIC caused by strategic coalition and joining efforts of agent 2 and 15 leading to congestion effects.

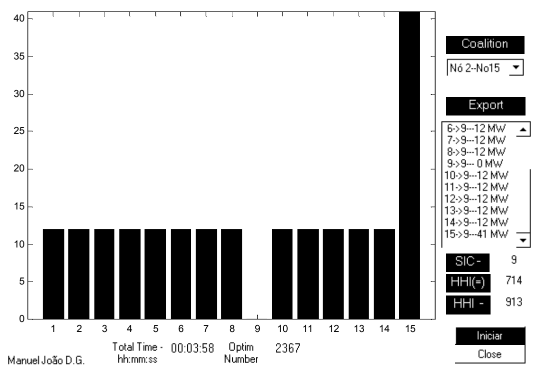

Fig. 5. SIC results for 2 and 15 coalition

6. Conclusion

This paper deals with strategic coalition of two agents joining efforts to get some market power by means of forced transmission congestion. A possible method of detecting possible critical coalitions in open energy market is proposed. After detection and selection of possible critical coalitions a market power evaluation is performed.

The study was done in two different example network with positive results.

It is possible to conclude that the algorithm proposed provide important information in respect to the possibility of strategic coalitions formation and how the establishment of them can affect the competitiveness and distribution of the energy market.

The SIC can give a quick and precise information of deformation in market share.

HHI values validate the selected coalitions.

Future improvements must be done in order to pre-select coalitions that do not represent any impact in SIC for all agents leading to less processing time.

The obtained information can be very important for increase of the knowledge of electric energy market under open access and competitive strategies. The ISO roll in modern electric energy markets is fundamental for the reliability, quality and competitiveness of al the system.

References

[1] G. Werden, "Identifying market power in electric generation", Public Utilities Fortnightly, p. 19, February 1996.

[2] J.S. Thorp, A.G. Phadke, "Protecting power systems in the post-restructuring era", IEEE Computer Applications in Power, Volume 12 No. 1, pp. 33-37, January 1999.

[3] John Hersey, "Opening up energy trading", IEEE Spectrum, pp. 54-58, January 2003.

[4] Zita A. Vale, Carlos Ramos, F. Maurício Dias, Isabel Praça, "Electricity market simulation: a multi-agent approach", Porto Power Tech 2001, Porto, Portugal, 10-13 September 2001.

[5] B.F. Hobbs, "LPC models of Nash-Cournot competition in bilateral and POOLCO-based power markets", IEEE Trans. Power Syst. Vol. 16, no. 2, pp. 194-202, 2001.

[6] R.D. Christie, B. F. Wollenberg and I. Wangensteen, "Transmission management in the deregulated environment", Proceedings of the IEEE, vol. 88, No.2, pp. 170-195, February 2000.

[7] S. Borenstein, J. Bushnell, and F. Wolak, "Diagnosing market power in california's deregulated wholesale electricity markets", Power Conference, paper PWP-064.

[8] W. Mielczarski and G. Michalik, "Open Electricity Markets in Australia: contact and spot prices", IEEE Power Engineering Review, pp. 49-51, February 1999.

[9] J.C. Dalton, "Assessing the competitiveness of restructured generation service markets: an

international comparison“, Electricity Journal, vol. 10, no. 3, April 1997.
[10] F.M. Scherer, “Industrial market structure and economic performance”, Rand McNally College publishing Company, 1980.
[11] North American Reliability Council, “NERC PTDF and TPF Viewer”, 12 June 1997.
[12] I.Otero Novas, C. Meseguer, J.J. Alba, “An iterative procedure for modelling strategic behaviour in Competitive Generation Markets”, 13th PSCC, 28 June – 2 July, pp. 251-257, Trondheim, 1999.
[13] NERC, “Transmission transfer capability”, May 1995.
[14] F.L.Alvarado, “Market power: A dynamic definition”, Bulk Power Systems Dynamics and Control IV: Restructuring Conf., Santorini, Grece, August 1998.
[15] Shu Tao and George Gross, “A congestion-management allocation mechanism for multiple transaction networks“, IEEE Transactions on Power Systems, vol. 17, no. 3, pp. 826-833, August 2002.
[16] G. Gross and S. Tao, “A physical-flow-based approach to allocating transmission losses in a transaction framework“, IEEE Transactions on Power Systems, vol. 15, pp. 631-637, May 2000.
[17] Shangyou Hao, Dariush Shirmohammadi, “Congestion management with ex ante pricing for decentralized electricity markets“, IEEE Transactions on Power Systems, vol. 17, no. 4, pp. 1030-1036, November 2002.
[18] Isabel Praça, Carlos Ramos, Zita A. Vale, Manuel Cordeiro, “Strategic agents in multi-period negotiation electricity markets”, IASTED International Conference on Artificial Intelligence and Applications, Málaga, pp. 411-416, 9-12 September 2002.
[19] Manuel João D. Gonçalves, Zita A. Vale, “Market power analysis – strategic coalition impact on market power”, 2002 IASTED in Proc. 2002 IASTED Euro PES 2002 International conference on Power and Energy System, pp. 16-21, June 2002.