MARKET POWER DETECTION – SIMULTANEOUS INTERCHANGE CAPABILITY EVALUATION UNDER TRANSMISSION CONGESTION

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Abstract – Electric power market is under a rapid changing process world-wide. This new perspective, has given rise to competition with the goal of price fall and market domination. In general, market power is the ability of a particular seller or group of sellers to maintain prices profitably above competition levels for a significant period of time. The paper deals with transaction power tracing in the transmission system in order to evaluate simultaneous interchange capability under forced congestion effects. A method for detection of sellers combined strategies actions is proposed and impact on market distribution is evaluated.

Keywords: Electricity market, market concentration, simultaneous interchange capability, power transfer distribution factors, congestion.

I. Introduction

Recent regulatory reforms in the power industry require the creation of electricity markets. The goal of the new structure is to make generation competitive while transmission system remains a regulated part of the system. Lower prices and innovation is supposed to be the result of new market structure. Nowadays the principal electrical energy markets have a philosophy of high competitive market in witch every agent can sell energy to other agents [1], [2].

The emergent electricity market structure is more akin to oligopoly than perfect market competition. An oligopoly is a market structure where few sellers, of significant size, can influence in a strong way the overall market [3]. Transmission constrains and congestion can isolate consumers from effective reach of some sellers, and transmission losses can discourage consumers to purchase from distant suppliers [4]. This kind of situation can give rise to market power.

Market power is harmful to competition and it is important for the independent system operator (ISO) to detect and penalise this kind of actions. There are many definitions of market power. Market power can be defined as the ability of a seller, or group of sellers, to drive the spot price over competition level, control the total output, takes off accessibility of other sellers to a specific and relevant market for a significant period of time. Market power can prevent competition in power production, service quality and technological innovation. In terms of the all net it will give rise to wealth transfer from buyers to some sellers by a misallocation of resources [5].

Market power can be exercised in a intentional or accidental way. For example, in generation sector, market power can arise for offering an excessive amount of generation to a market, by committing more costly generation units instead of less expensive ones, or by transmission constrains that could limit the transfer capability of some sellers to a specific market (zone) [6]. If the first two are considered to be intentional the last used to be considered accidental. In fact new strategic coalition can make this way to get market power no accidental. Transmission constrains could prohibit certain generation units from supplying power and persuade dominant providers to drive market prices up by offering more costly units to market [7].

Authorities in the electricity industry must identify, detect, evaluate and take decisions to correct and penalise this companies owing some market power.

The transmission system stills plays an important role in the power system and directly depends from the ISO. Because transmission system constrains can be important source of market power, many models of strategic interaction on networks have been developed [8].

Congestion occurs whenever the transmission network is unable to accommodate (line limits violation) all the desired transactions due to violation of one or more constrains for the resulting power flow both for base case and for a set of specific contingencies. The open access transmission system witch, in turn, leads to more frequent congestion situations. The task of congestion management requires the ISO to identify and take decisions in order to relieve such situations throughout the deployment of various physical or financial mechanisms [9], [10].

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 this paper, some studies to make a quick and precise evaluation of market power and market concentration due to strategic coalition are proposed according to a specific image of the power market.

II. Congestion Management

Congestion occurs whenever the system state of the grid is characterised buy one or more violations of the physical, operational, or policy constrains under witch the grid operates in the normal state or under anyone of the contingency cases in a set of specified contingencies. Congestion is associated with a specific point in time. In the old vertically integrated industry, the generation, transmission and generation where, commonly owned, controlled and operated by a single entity. The central operator would dispatch the system having full knowledge of operational costs and system constrains. In this case congestion was not a term that was used. Usually the problem was solved running an optimisation problem subject to various constrains considered. The optimal power flow (OPF) tool was developed to find optimal solution of this problem. The result was a tool that gives a fine-best solution maximising the social surplus or minimising the total production costs.

But the new open access structure brings new all variety of uses of the transmission system than those for witch it was originally planned and designed. The ISO is responsible for determining the necessary actions to ensure that no violations of the all grid constrains occurs. It is this set of actions and procedures that is referred to as congestion management (CM). This kind of actions is mainly the redispatch of the generation and load levels so as to establish a system state without constrain violations.

Pricing congestion plays a major role in attaining such a state. The operation of a competitive electricity market takes place, typically in two distinct stages:

- Market dispatch (MD),
- Congestion redispatch (CR).

Market dispatch refers to the stage when participants submit forward market bids and offers as the basis for the determination of the generation and demand profiles for the market horizon [11]. Power exchange (PX) uses their portfolios of resources and loads to prepare balanced supply-demand schedules that are submitted to the ISO.

When the market dispatch creates a non feasible state of operation due to constrain violation, the ISO invokes the second stage - CR. The actions involved are out-of-merit dispatch and buy back power from generators in order to compensate congestion [12].

Some works on CM mechanisms aided to define the rules for the emerging competitive markets with special attention to the Pennsylvania-Jersey-Maryland (PJM) ISO and California ISO [13].

One important issue is the applicability of the OPF to competitive markets reflecting the several problems constrains.

III. Market Power Evaluation

A. *Sources of Market Power*

Market power can appear in two main forms: by market dominance and by transmission constrains. The market dominance is the market power of an 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 has allowed two dominant sellers – National Power and Power Gen.

Transmission constrains is the case closely analysed in this paper, and reflects the existence of transmission congestion due to combined suppliers actions. A supplier can profit from increasing, rather than decreasing, production in specific points of the network, to create artificial line congestion, limiting the access of the competitors to a specific market.

Congestion can, in fact, create conditions of market inefficiency in a short-term scenario. It is said that transmission systems introduce a degree of inefficiency into electricity markets [5].

B. *Market Power in Electricity Markets*

Great price increase is an intuitive manifestation of market power, such as drastic price increase during some periods is 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.

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 [14].

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:

- Market share,
- Market concentration,
- Elasticity of demand,
- The amount and distribution of excess capacity,
- Process of establishing prices,
- 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:

- Identification of relevant products and services,
- Identification of the geographical situation of the market,
- Analysis of market share and market concentration,
- Estimation of pricing behaviour through simulation analysis,
- Oligopoly equilibrium analysis.

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 analyse 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 [15]. The most used process is to calculate the so-called HHI index (Herfindahl-Hirschman Index) .

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).

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

p_i - percentage of market owned by each participant.

For example, for five suppliers represented in Figure 1 with shares of 18, 12, 40, 18 and 12 percent the HHI would equal 2536 ($18^2+12^2+40^2+18^2+12^2$) in contrast with HHI=2000 corresponding to equal share.

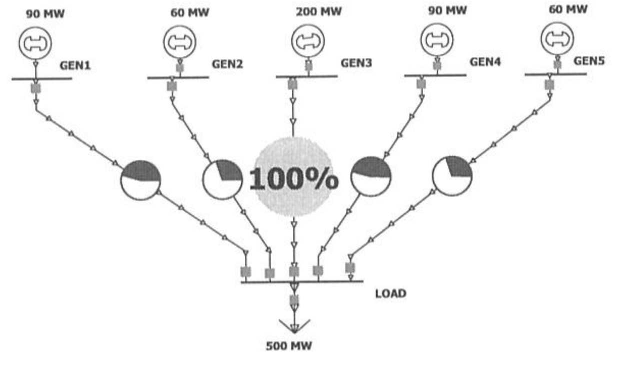

Figure 1- 5 bus example

In the case of one generator having the totality of the Market Power the HHI calculation assumes its maximum value of 10000 ($100^2+0+0+0+0$).

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.

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:

- Gives proportionately greater weight to the market share of the larger suppliers,
- Takes into account of all suppliers in the market.

IV. Distribution Factors

Distribution factors are calculated on linear load flows [16].

In general, generation distribution factors have been used mainly in security and contingency analyses. This kind of factors allows determining the impact of generation and load on transmission flow. Nowadays these factors are used in transmission payments allocation in restructured systems. This factor can in a efficient and quick way evaluate the impact of a given generation shift on the power flow in a given line.

A. *Generation Shift Distribution Factors (A factors)*

These factors provide line flow changes due to a change in generation, and are defined as in (2).

$$\begin{cases} \Delta P_{hk} = A_{hk,i} \cdot \Delta P_{Gi} \\ \Delta P_{GR} = -\Delta P_{Gi} \end{cases} \qquad (2)$$

ΔP_{hk} - change in active power flow in line h-k,
$A_{hk,i}$ - A factor of line h-k due to change generation in node i,
ΔP_{GR} - change in generation in reference node,
ΔP_{Gi} - change in generation in node i.

A factors measure the incremental use of transmission network by generators and loads. A factors are dependent of the reference bus choice and independent of operational conditions of the system.

B. *Generalised Generation Distribution Factors (D)*

These factors give the impact of each generator on active power flow, so they can bee negative as well. Since they are calculated in a linear approximation (DC model) they can be only used in order to active power flow. They are defined as in (3).

$$\begin{cases} P_{hk} = \sum_{i=1}^{N} D_{hk,i} \cdot P_{Gi} \\ D_{hk,R} = \dfrac{\left[P_{hk} - \sum_{\substack{i=1 \\ i \neq R}}^{N} \left(A_{hk,i} \cdot P_{Gi} \right) \right]}{\sum_{i=1}^{N} P_{Gi}} \\ D_{hk,i} = D_{hk,R} + A_{hk,i} \end{cases} \qquad (3)$$

P_{hk} - active power flow in line h-k,
$D_{hk,R}$ - D factor of line h-k due to generation in reference node,
$D_{hk,i}$ - D factor of line h-k due to generation in node i.

This factor measures the total use (not incremental) of transmission network facilities produced by generators injections. This factor depends on line parameters, system operation and independent of reference bus choice.

C. *Tracing methods (Bialek method)*

There are several tracing methods. In Bialek method is assumed that nodal inflows are shared proportionaly among nodal outflows [17]. In this method the distribution factors are calculated as in (4).

$$\begin{cases} D_{hk,i} = \dfrac{P_{hk} \cdot [A_u]_{hi}^{-1}}{P_i} \\ [A_u]_{ij} = \begin{cases} 1 & i = j \\ -\dfrac{|P_{ji}|}{P_j} & j \in \alpha_i \\ 0 & Otherwise \end{cases} \end{cases} \quad (4)$$

$D_{hk,i}$ - D Bialek factor of line h-k due to generation in node i,
P_{hk} - Power flow in line hk,
A_u - Distribution matrix upstream,
P_j - Injected power in node j (generation-load),
α_i - Set of nodes supplying directly bus i.

Figure 2 presents the first example network used in these studies. In this nine bus example network:

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

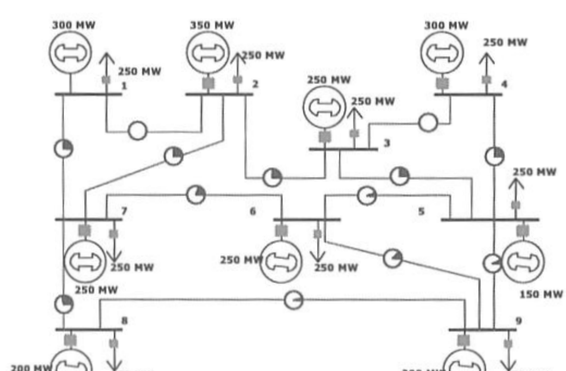

Figure 2- 9 bus example network

Figure 3 shows the contributions of each generator (MW) for line 7-8 active power flow using D factors (total of 58,6 MW).

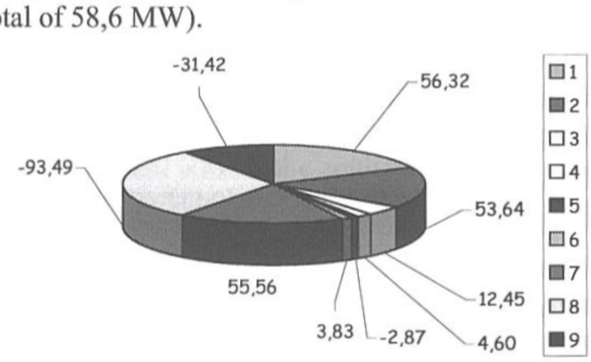

Figure 3- Contribution of each generator for line 7-8

V. Power Transfer Distribution Factor

The evaluation of the distribution of power market can be done using the power transfer distribution factors (PTDF) associated to a specific power transfer direction between two points – selling point and buying point. These factors express, in a linear approximation, the way a given transaction can affect the power flow in each of the lines on the network. The regular calculation of the PTDF is used by the ISO to validate transactions according to the physical limits of the lines.

For a specific transaction, the PTDF calculation can be done. If node *i* is selling to node *j* P_{ij} MW the PTDF for each line can be calculated as in (5).

$$P_{hkij} = P_{hk} + PTDF(h,k,i,j) \cdot P_{ij} \quad (5)$$

P_{hkij} - Active power flow in line hk after a new transaction between ij,
P_{hk} - Active power flow in line hk before a new transaction between ij,
P_{ij} - Transaction between ij.

VI. Proposed Market Evaluation

One way to evaluate the market share is to obtain the SIC (Simultaneous Interchange Capability) for each participant. This parameter traduces the maximum ability a specific agent has to sell power to some market.

The SIC calculation gives a precise idea of how much power (maximum) an agent can sell to a precise market dealing with all the constrains in the network. This value depends on the network topology and conditions (generation, load, node voltage,…). The congestion effects will be included in this proposed study in a pessimistic approach (maximum impact). Considering the congestion effects the algorithm proposed can be described in the following steps:

- 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,
- For each coalition calculate the new transmission capacity limit for each line,
- Make SIC calculations with the new line limits,
- Select the coalitions that affect the accessibility to the market for other agents,
- Calculate the HHI for each detected critical situation.

A. *New Transmission Line Limits*

If some agents control their individual generation in order to maximise their access to a given market, by limiting the access of the others, transmission line congestion is created. In fact, it is possible that by generation reconfiguration actions, some lines in the network become overloaded creating congestion zones modifying the market share.

Two agents can join efforts keeping their joint production unaltered and creating artificial congestion effects. Active power transmission limit is reached leading to a rise in market concentration.

In the proposed study only two agents coalition is considered. The proposed calculation method uses a DC model and Power World Simulator (for visualisation) combined with MatLab.

For this, it is necessary to solve an optimisation problem represented in (6).

$$máx\left(P_{hk}\right) = máx\left[D_{hki} \cdot P_{Gi} + D_{hkj} \cdot P_{Gj}\right] \qquad (6)$$

$$Sub.to$$

$$\begin{cases} \sum_{k=i,j} \Delta P_{Gk} = 0 & \text{JOINT PRODUCTION} \\ P_{Gkmin} \leq P_{Gk} \leq P_{Gkmáx} & \text{GENERATION LIMITS} \end{cases}$$

P_{hk} - Active power flow in line hk,
D_{hki} - Distribution factor for line hk due to generation i,
P_{Gi} - Generation in node i,

After optimising this problem for all lines it is possible to evaluate the new power transmission limits for each line due to artificial congestion [18].

The upper and lower limit variation of active power (both ways) for each line after combined action leading to congestion effects can be calculated as in (7).

$$P_{hk} \leq \left[P_{hk\,máx} - \left(P_{hkcong.} - P^{0}_{hk}\right)\right] \qquad (7)$$

$$P_{hk} \geq \left[-P_{hk\,máx} + \left(P_{khcong.} - P^{0}_{kh}\right)\right]$$

P_{hk} - Active power flow in line hk,
$P_{hkmáx}$ - Active power limit in line hk,
P_{hkcong} - Maximum active power flow after generation reconfiguration actions,
P_{hk}^{0} - Initial active power flow in line hk.

B. SIC Evaluation

Results where obtained for two example networks. For the 9 bus example network, presented in Figure 2, and for the 15 bus example network that is represented in Figure 4 with equal simplifications considered for the 9 bus example network.

In both examples the market that was considered was the ability to sell to node 9 (max. import of 200 MW).

Of course for another network dispatch the results obtained would be different. First, the SIC value is calculated for the initial network without congestion effects. In such situation all the agents have equal opportunity to sell power to agent 9 [18].

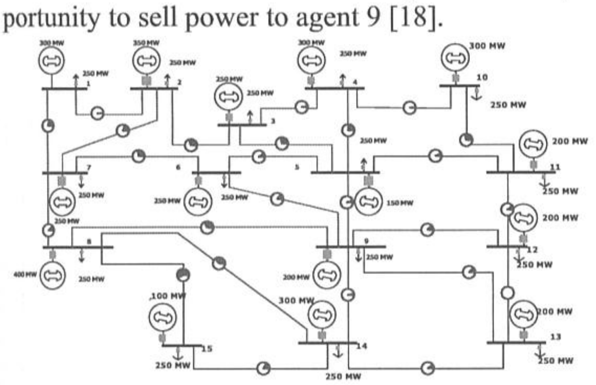

Figure 4- 15 bus example network

The SIC value is obtained by (8) searching the optimal solution (maximum) of function exportation to the buying node. In this case we will include the new line limits due to existence of coalition.

$$EXP = máx\left[\sum_{i=1 \neq 9}^{N} \Delta P_{Gi}\right]$$

$$Sub.to \qquad (8)$$

$$\begin{cases} \sum_{i=1 \neq 9}^{N} \Delta P_{Gi} = P_{G9} \\ \sum_{i=1 \neq 9}^{N} PTDF((h,k,i,9)) \cdot \left(P_{Gi} + \Delta P_{Gi}\right) \leq \left(newP_{hk\,máx}\right) \\ \sum_{i=1 \neq 9}^{N} PTDF((h,k,i,9)) \cdot \left(P_{Gi} + \Delta P_{Gi}\right) \geq \left(newP_{hk\,máx}\right) \\ \Delta P_{Gi} \geq 0 \quad \text{each node} \end{cases}$$

ΔP_{Gi} - Variation in generation i,
P_{Gi} - Initial generation in i,
EXP - Exportation to node 9.

The starting point for the used linear programming algorithm is the solution that corresponds to equal opportunity for each agent.

C. Results

For the two networks analysed the results show that this kind of action can create deformations in the market share.

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 exportation of 25 MW for each node.

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:

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.

- For each coalition calculate the new transmission capacity limit for each line,
- Make SIC calculations with the new line limits,
- Select the coalitions that affect the accessibility to the market for other agents,
- Calculate the HHI for each detected critical situation.

For the proposed 9 bus example network the results of SIC calculations can be observed in Figure 5 and Figure 6.

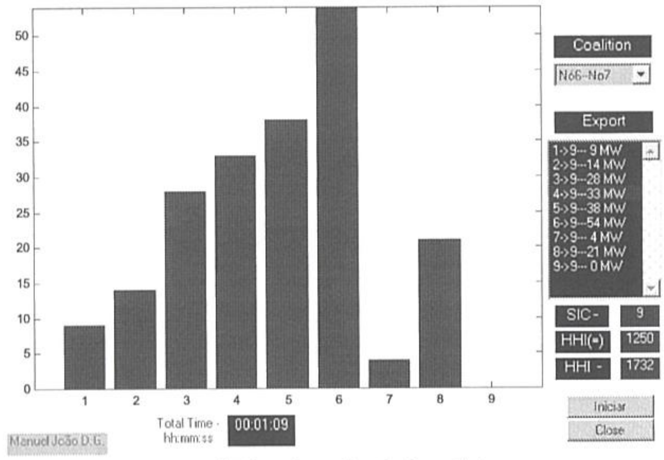

Figure 5- SIC values for 6-7 coalition

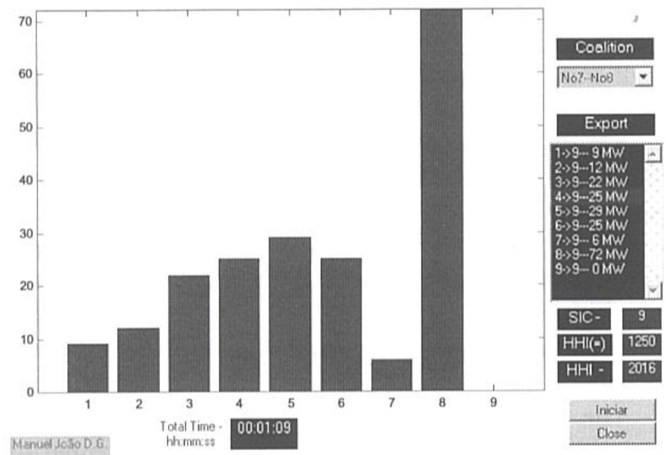

Figure 6- SIC values for 7-8 coalition

Table I shows the HHI values for the detected critical coalitions in the 9 bus example network.

Table I- 9 Bus HHI values for detected critical coalitions

Coaliti-on	Market Share (%)	Total EXP (MW)	HHI
1<<>>8	37	200	1729
4<<>>8	23	200	2207
6<<>>7	29	200	1732
7<<>>8	39	200	2016

It is possible to see that this coalition, by congestion constrains of the transmission system, manage to restrict the access of the others to the market. For equal opportunities the market share for each participant would be 12,5% but the colligated agents will beneficiate with their actions. It is possible to see an increase in Herfindahl -Hirschman Index witch confirms the strong deformation in market distribution, in presence of this strategic behaviour.

For the proposed 9 bus example network the results of SIC calculations can be observed in Figure 7 and Figure 8.

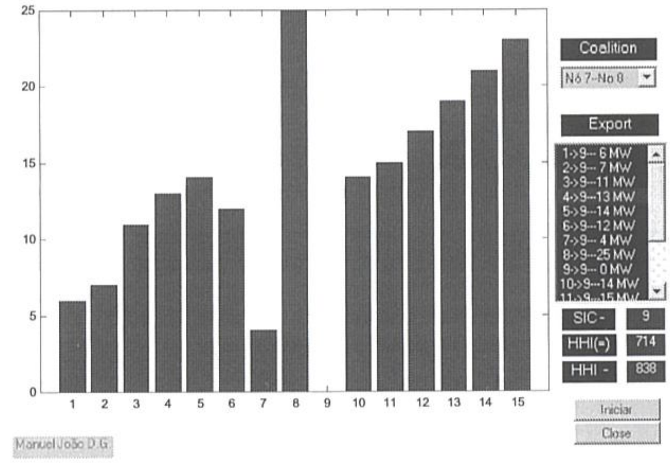

Figure 7- SIC values for 7-8 coalition

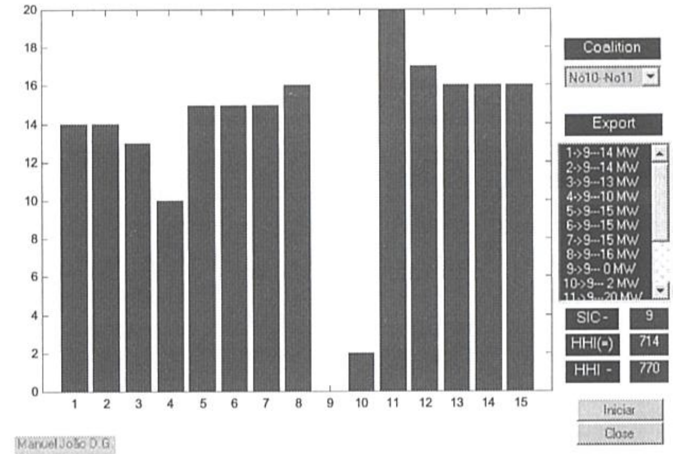

Figure 8- SIC values for 10-11 coalition

VII. Conclusions

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. In fact, it is possible to see that market share can be in risk if joint actions of agents is introduced. If the study is extended to the possibility of combined action of more than two agents the congestion effects in the transmission system would be more intense creating more deformation in SIC values and giving greater values for HHI giving rise to more market power.

It is possible to conclude that in a high dimension network the possibility of creating artificial congestion effects would be not so strong. Comparing the two examples it can be concluded that for 15 bus example network the number of cases is much higher but the detected critical coalitions is more limited. The increase in network paths limits the ability of two agents to perform this kind of actions and exercise market power.

For a high dimension network we can talk about a influence zone of the two coalition agents that is limited by the physical dimension of the network.

Future improvements must be done in order to preselect 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.

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