STRATEGIC COALITION IMPACT ON TRANSMISSION COSTS

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Abstract – In a liberalized electric power market one of the main goals is equal opportunity of market and network access for each participant. However, the possibility of agents (sellers) strategic coalition actions can limit the accessibility of some participants to the market. This kind of actions can affect the transmission network use allocated costs for each transaction. These costs are divided in a different way that can penalize the sellers outside the strategic coalition. In this paper we present a comparative study of transmission costs allocated to each seller in a scenario with and without transmission congestion effects due to coalitions of two sellers. The paper includes a case study considering coalition scenarios selected after a power market evaluation.

Keywords: Electricity market, power market, transmission cost, embedded methods, congestion.

I. INTRODUCTION

In a context of liberalization of Electric Energy markets, the electrical network is one of the elements of this market that is assumed as a natural monopoly. This is due to the physical and economic impossibility of the existence of several alternative infrastructures as transmission networks. So that this monopoly does not constitute an obstacle for the activities of the agents who act in these markets, the existence of adequate regulation that guarantees the access to the transmission electrical network is required. This access must be carried out through a clear way. However, the regulation must also guarantee the economic viability of the electrical network concessionaires companies.

This paper presents a study on the quantification of the use of the transmission electrical network using different methodologies from those used for regulation purposes. In result of this quantification, the calculation of the taxes allocated to each user of the transmission electrical network is carried out. The calculation of these taxes is based on a diversified set of techniques, which are part of the Embedded Methods, which are used in the study presented in this work. This study has involved simulations based on the following methods: MW-mile, Module or Use and Dominant Flow. The calculated taxes depend, among others factors, on the active power flow, the sharing in these transits due to each transaction and on the total system cost [1].

One of the most important aspects in the energy market is the allocation of the involved costs of production, transmission and distribution. Among these, the transmission costs are highly significant in long lines with possibility of expansion.

The transmission costs associated to any energy transaction are divided in several instalments such as: operational costs, opportunity costs, expansion costs of the network and existing costs of the system. The aim of the quantification of these costs is to make the electric network to be paid by who uses it. This means that the costs must be supported by all the users of the network of transmission, according to the shares of its use.

There are several approaches for the allocation of remunerations to be paid to the transmission network, such as marginal cost, incremental cost and embedded cost methods. In this work the embedded methods are applied [2].

Recent regulatory reforms in the power industry require the creation of electricity markets. The new structure makes generation competitive while the transmission system remains a monopoly of the system. Lower prices and innovation are supposed to be the results of the new market structure. Nowadays the main electrical energy markets have a philosophy of high competitive markets in which every agent can sell energy to other agents [3], [4].

The emergent electricity market structure is more akin to oligopoly than to perfect market competition. An oligopoly is a market structure where few sellers, of significant size, can influence in a strong way the overall market [5]. Transmission constrains and congestion can isolate consumers from effective reach of some sellers, and transmission losses can discourage consumers to purchase from distant suppliers [6]. This kind of situation can give rise to market power.

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 situation of the power market. Critical coalition selection is made and transmissions costs allocation for initial network and for new conditions due to critical strategic coalition effects. In this proposed method the transmission costs allocation methods used are the following: MW-Mile, Module and Dominant Flow, applied to a nine bus example network.

II. Market Power

Non-competitive practices in electricity power industry, especially in the generation sector, mainly concern market power. When an owner of a generation facility is able to exert a significant influence (monopoly) on pricing or on the availability of electricity this can create a strong evidence of market power. Market power can prevent the competition and the costumer choice in a liberalized power system. Market power is harmful to competition, being 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, limiting 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 market, it will give rise to wealth transfer from buyers to some sellers by a misallocation of resources [7].

Market power can be exercised in an intentional or accidental way. For example, in the generation sector, market power can arise from 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 area [8]. If the first two are considered to be intentional the last used to be considered accidental. But, in fact, new strategic coalition can make this way to get market power not 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 [9].

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 still plays an important role in the power system and directly depends from the ISO. Because transmission system constraints can be an important source of market power, many models of strategic interaction on networks have been developed [10].

A. Sources of Market Power

Market power can appear in two main forms: by market dominance and by transmission constraints. 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 [10].

The situation of transmission constraints 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 reconfiguring the 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. In conclusion transmission systems can be responsible for a degree of inefficiency into electricity markets [7].

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[11].

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 [11].

C. Market Power Analysis

Many factors should be taken in account when evaluating the competitiveness of an electricity market. These factors include, market share, market concentration, elasticity of demand, the amount and distribution of excess capacity, process of establishing prices and transmission system limitations .

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

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

Market power can be evaluated based on 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 an effective and easy way to find the existence of market power [12].

The most used process is to calculate the so-called HHI index (Herfindahl-Hirschman Index). The HHI is calculated for a specific market and traduces the accessibility distribution of the participants to the market.

In a N participants 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 participant i.

The HHI approaches 0 when there is a large number of very small suppliers and equals 10000 when there is just one. HHI gives greater weight to the market share of the large suppliers while taking in account all suppliers in the market.

The HHI method for market power analysis has played a prominent role for the FERCs (Federal Energy Regulatory Commission) decision in respect of electricity suppliers merging [13].

The HHI method has the advantage of simplicity with the drawback that it has no supporting theory being 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 all suppliers in the market.

Some studies where performed for a nine bus example network in order to detect, by market power analysis, possible strategic coalitions that can be harmful to market equilibrium. Strategic coalitions of sellers (by generation reconfiguration actions) can affect the overall accessibility to a specific market of the other participants [13]. This kind of actions can, by means of transmission network congestion, partially isolate some areas and create situations of highly distorted HHI values (market concentration), and can contribute in a strong way to a transfer of transmission costs from market power owners to other sellers. In this paper it is proposed a study in order to evaluate the impact on transmission costs allocation under strategic coalition effects.

III. Transmission Costs

In the competitive electric energy market it is important to quantify efficiently the costs associated to each activity in the sector [1].

The main costs associated to the market of electric energy are the costs of production, costs of transmission and costs of distribution. This paper allocates the transmission costs, associated to a wheeling transaction. For calculation of the taxes to be allocated for each transaction R(u) the embedded methodology was used. The development tools used are: Matlab for implementation of the embedded methods and the Power World simulator to carry out the simulation of Power Flow.

In the embedded methods all system costs, (existing transmission system, operating and expansion) are considered, these costs are allocated among system users in proportion to their "extent of use" of the transmission resources.

Allocation methodologies differ on their definition and measure of this "extent of use". They can be classified as: load flow based methods such as MW-Mile and Dominant Flow; rolled-in methods such as Postage Stamp methodology [14]. The main difference between the Postage Stamp, MW-Mile and Dominant Flow methods is that: the MW-Mile and Dominant Flow use the evaluated values of power flows in its implementation, while the Postage Stamp method does not use these values. In this paper, only MW-Mile and Dominant Flow, methods are considered.

In the remaining of this paper analysis, the following variables and expressions are used:

k - Line that connects bus i to bus j

C_k - Cost of line k, (kEuro)

FM_k - Line k capacity (MW)

F_k - Flow in line k in the initial conditions (MW)

L_k - Length of line k (km)

$CT = \sum_k C_k$ - Total cost of transmission (kEuro)

$F_k(u)$ - Impact of transaction u in line k (MW)

$W(u)$ - Power of transaction u (MW)

$R(u)$ - Allocated cost to agent u (kEuro)

$PG(g)$ - Power produced by generator g.

A. MW-Mile

The MW-Mile method is an embedded cost method that is also known as a line-by-line method because it considers, in its evaluations, changes in MW transmission flows and transmission line lengths in miles [14]. The method evaluates charges associated with each wheeling transaction based on the transmission capacity use as a function of the magnitude of transacted power, the path followed by transacted power, and the distance travelled by transacted power. The MW-Mile method is also used in identifying transmission paths for a power transaction. As such, this method requires dc power flow calculations. The MW-Mile method is the first pricing strategy proposed for the recovery of fixed transmission cost based on the actual use of transmission network.

The method guarantees the full recovery of fixed transmission costs and reasonably reflects the actual usage of transmission systems.

The following algorithm is used in the MW-Mile method to estimate the usage of firm Transmission services by wheeling transactions:

1) For each transaction u:

- Use a nodal power injections involved in transaction u, calculate transaction-related flows on all network lines using an approximate (dc) power flow model;
- The magnitude of MW flow on every line is multiplied by the length of the line (in $/MWmile), and summed over all the lines.

2) Repeat the process for other transactions

The contribution of transaction u to the total transmission capacity cost is calculated as follows: transmission facility costs are allocated in proportion to the ratio of flow magnitude (absolute value) contributed by transaction u and the sum of absolute flows caused by all transactions, as given by the equations (2) and (3).

$$P = \frac{CT}{\sum_k |F_k| \times L_k} \qquad (2)$$

$$R(u) = \sum_k P \times |F_k(u)| \times L_k \qquad (3)$$

B. Dominant Flow

The Dominant Flow method joins two methods: Module or Use and Zero Counterflow.

The Module or Use method distributes the total cost of the system for the different transactions, considering transactions in both directions. In this way, all transactions pay, but the cost is more distributed, becoming cheaper for the cases where the transaction reduces the flows in the lines. The expression (4) shows how to determine the tax to be paid for the R(u) transaction [1].

$$R(u) = \sum_k C_k \frac{|F_k(u)|}{\sum_s |F_k(s)|} \qquad (4)$$

The Zero Counterflow method only taxes the positive flows. This method assumes that the negative flows are useful for the network, therefore in these cases the transactions are not paid but they do not receive any credit. The expression (5) shows how to determine the tax to be paid for the R(u) transaction [1].

$$R(u) = \begin{cases} \sum_k C_k \frac{F_k(u)}{\sum_s FD_k(s)} & \text{for } F_k(u) > 0 \\ 0 & \text{for } F_k(u) \le 0 \end{cases} \qquad (5)$$

With:

$$FD_k(u) = \begin{cases} F_k(u) & \text{if } F_k(u) > 0 \\ 0 & \text{if } F_k(u) \le 0 \end{cases} \qquad (6)$$

The function $FD_k(u)$ in (6) only considers the impact, provoked by the transaction *u* in line *k*, when this increases the active power flow in this line.

The Dominant Flow method considers that R(u) is the addition of two taxes RA(u) and RB(u) in (7),(8). The tax RB(u) is determined using the Zero Counterflow method substituting cost C_k for CB_k. The tax RA(u) is evaluated using the "Module or Use" method where C_k is substituted by CA_k as in (9). Factor CB_k corresponds to the cost due to the transit in the line for the base case of the system and CA_k corresponds to the cost of the non used capacity.

$$R(u) = RA(u) + RB(u) \qquad (7)$$

Where:

$$\begin{cases} RB(u) = \begin{cases} \sum_k CB_k \frac{F_k(u)}{\sum_s FD_k(s)} & \text{For } F_k(u) > 0 \\ 0 & \text{For } F_k(u) \le 0 \end{cases} \\ RA(u) = \sum_k CA_k \frac{|F_k(u)|}{\sum_s |F_k(s)|} \end{cases} \qquad (8)$$

$$\begin{cases} CA_k = C_k \frac{FM_k - F_k(u)}{FM_k} \\ CB_k = C_k \frac{F_k(u)}{FM_k} \end{cases} \qquad (9)$$

With this method all the participants that use the system in the opposite direction of the resultant flow receive an incentive, which consists of lower cost. This incentive increases when the system is more loaded, arriving to zero cost when the system is on maximum load. These economical signs are coherent with the intents of reducing expansion costs.

IV. CASE STUDY

Figure 1 presents the example network used in these studies.

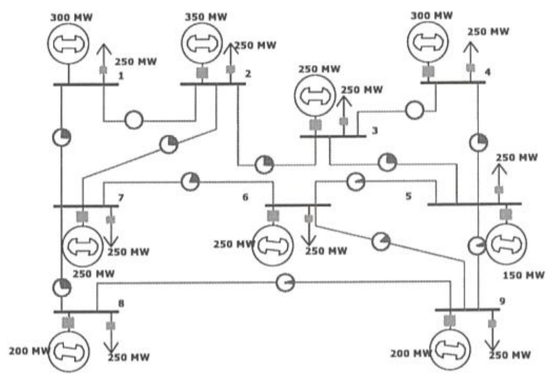

Figure 1- 9 bus example network

In this nine bus example network:

- Each node has a generator with maximum 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).

The case study proposed in this paper includes two parts.

The first deals with detection of critical coalitions affecting market distribution.

The second part uses the detected cases and compares the transmission costs for each transaction in initial situation and under congestion effects.

Figure 2 shows a block diagram of the different parts of the proposed study.

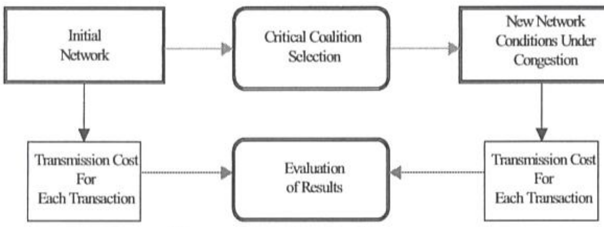

Figure 2- Block diagram

A. *Critical Coalition Detection*

The first stage of the proposed case study deals with critical coalition detection. The evaluation of impact on market share due to each coalition was obtained by the SIC System Interchange Capability) parameter. The SIC represents the maximum amount of active power (export power) that can flow, on the system under given conditions, between a specific pair of Seller-Buyer. This value depends on the network topology and conditions (generation, node voltage, load,…).

First, generation distribution factors for each generator and line are evaluated in order to quantify the impact on each line for a given shift in generation.

The congestion effects will be included in a pessimistic approach because maximum impact on lines is considered. For a given sellers coalition new line limits are evaluated by means of generation shift in each generator.

The impact on accessibility to a given market is evaluated by SIC calculation. For a non critical coalition the SIC must be equal for every sellers reflecting a low HHI value. The coalitions that affect the distribution of the SIC value are considered critical and must be taken into account by the ISO as possible sources of market power. 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.

The SIC value is obtained by (10) 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.

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

$$Sub.to \qquad (10)$$

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

ΔP_{Gi} - Variation in generation i,

P_{Gi} - Initial generation in i,

$PTDF(h,k,i,9)$ - Power Transfer Distribution Factor on line h-k due to exportation from i to 9,

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. The first restriction reflects the sum of all exportations being equal to consume of node 9 (selected market).

The second and third restrictions represent the limits impose by maximum capacity of each line on both ways on presence of strategic forced congestion effects.

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

Coalition	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

Using this information it is possible to reconfigure the initial example network conditions (generation), without violating any previous established contract, and evaluate the impact in line flows due to coalition actions. In this study the selected coalition was combined efforts of sellers 1 and 8.

In this case the new conditions for the example network can be seen in Figure 3. The total generation of the two sellers stays unaltered but the reconfiguration in joint generation fixes injection in bus 1 at 0MW and injection in bus 8 500 MW.

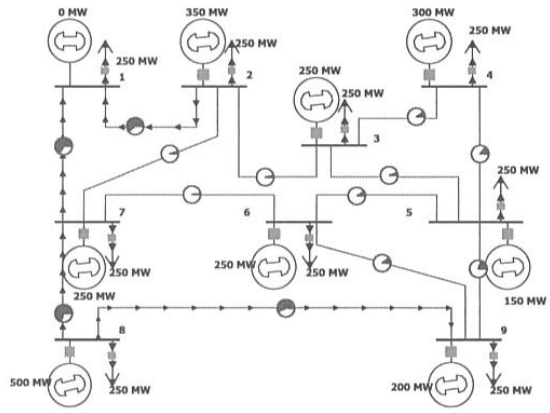

Figure 3- Example network after 1-8 coalition actions

B. Transmission Costs Evaluation

For transmission costs allocation, three methods were used: MW-Mile, Module and Dominant Flow. The results obtained are represented in Table II and Figure 4. Each generator is considered to be a seller and the transmission costs are allocated to each generator reflecting the transmission usage of each seller by injecting a certain amount of power, in the network, and so affecting the line flows. The total usage cost of the transmission network is 65707 kEuro. This cost is distributed in different ways by the three methods, as presented in Table II.

Table II- Transmission costs (Initial Network)

	G1	G2	G3	G4	G5	G6	G7	G8	G9
MW.Mile	10267	9841	7636	10001	4143	7764	6049	4764	5240
Module	9837	9159	7473	9788	4120	8534	5724	5040	6033
Dominant F.	10766	10293	7669	9940	3492	8066	5833	4556	5092

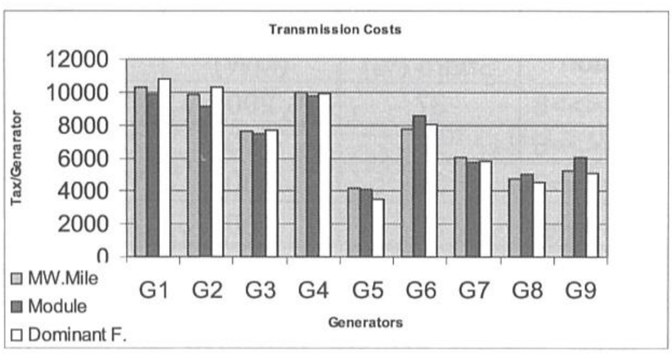

Figure 4- Transmission costs

After coalition actions the new transmission costs allocation are represented on Table III. This new situation deals with coalition of sellers 1 and 8. In this situation generator 1 injects 0 MW and generator 8 injects 500 MW. It is possible to verify that coalition actions of these two sellers transfer costs to the other participants. In fact, in Table II the cost allocated to G1 and G8 is 10267+4764 which is much grater than the one evaluated in Table III that is G1+G8= 12504 (MW-Mile). As the sum of all the transmission costs is the same in the two cases it is possible to conclude that the difference is transferred to other participants as shown in Table V.

Table III- Transmission costs (Reconfigured Network)

	G2	G3	G4	G5	G6	G7	G1+G8	G9
MW.mile	10332	8017	10500	4350	8152	6351	12504	5501
Módule	10838	8053	10248	4269	8473	6169	11925	5732
Dominant F.	10452	8047	10567	4013	8260	5792	12866	5708

Table IV presents the variation of transmissions costs allocated to each participant using the Dominate Flow method. Figure 5 shows the correspondent graphic.

In Table V is possible to evaluate the variation of transmission costs for each seller, taking into account that generator 1 and 8 are colligated. All the proposed transmission costs allocation methods give similar results.

Table IV- Transmission costs (D. Flow method)

	G2	G3	G4	G5	G6	G7	G1+G8	G9
Initial	10293	7669	9940	3492	8066	5833	15323	5092
Congested	10452	8047	10567	4013	8260	5792	12866	5708

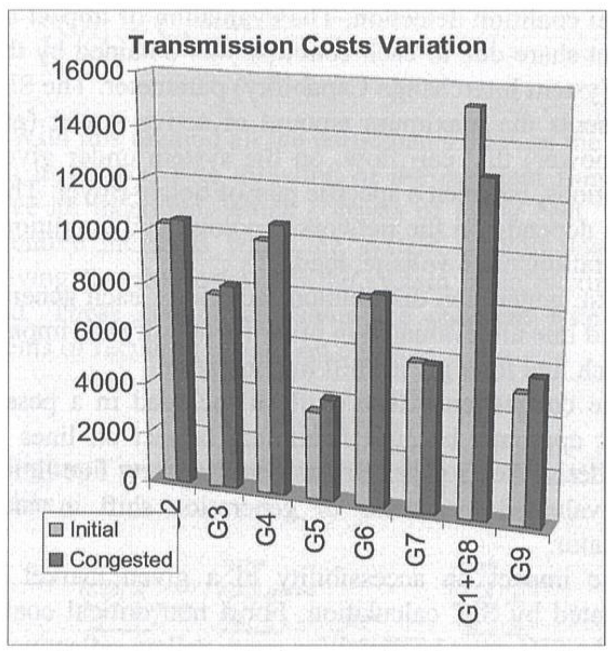

Figure 5- Transmission costs (D. Flow method)

Table V- Transmission costs variation

	G2	G3	G4	G5	G6	G7	G1+G8	G9
ΔMW.mile	491	381	499	207	387	302	-2527	261
ΔMódule Use	1679	580	460	149	-61	445	-2952	-301
ΔDominant F.	160	378	627	521	194	-40	-2456	617

V. 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 used. After detection and selection of possible critical coalitions one of the detected cases was closely analysed. The evaluated colligation was generator 1 and generator 8. Due to this fact it is possible to take conclusions analysing only one of the methods. The Dominant Flow method was chosen because it is the only one that takes into account the non used transmission capacity of the lines and the direction of the injected power flow by each generator on each transmission line.

The results show that besides the limitation of accessibility to market that colligated sellers make to others by their actions, they can, by means of line constrains, transfer part of their initial transmission system use taxes to the others sellers. All the other sellers have a positive variation and only colligated sellers profit with the artificial congestion effects created by their actions.

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 all the system.

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