A LINGUISTIC FUZZY METHOD TO STUDY ELECTRICITY MARKET AGENTS

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Abstract: The aim of this paper is to study the behavior of the agents that participate in the Spanish electricity market, for this purpose, the data that the Market Operator provides us after the period of confidentiality are analyzed. The objective is to know the operation to simulate the offerings of blocks the some of them. Market participants are companies authorized to participate in the electricity production market as electricity buyers and sellers. The economic management of the electricity market is entrusted to Iberico Market Operator of Energy (MO) (OMEL,). A fuzzy (Zadeh, 1965) method has been created. It is based on the hour and in the matches obtained of the previous day at this hour, and it is capable of model the behavior that is going to have an agent of the electric market in each hour. We try with this method to deal as the agents realize the offer of production, for it we take the information of three of them in June, 2004, the result of this work is understands better the standard that they are still and the logic of the offers of blocks that fulfil the pool.

1 INTRODUCTION

The electricity market is the set of transactions arising from the participation of the market agents in the sessions of the daily and intraday markets and from the application of the System Technical Operation Procedures. Physical bilateral contracts concluded by buyers and sellers are incorporated in the production market once the daily market has closed. We will analyze the daily market in this first work.

The purpose of the daily market, as an integral part of electricity power production market, is to handle electricity transactions for the following day through the presentation of electricity sale and purchase bids by market participants.

For the purposes of the presentation of electricity sale bids, a production unit is deemed to refer to any thermal generating set, pumping station, management unit of a hydro-electric power station or management unit of a group of wind generators of a wind park that unload their electricity for the same node of the network.

Buyers on the electrical power market are distributors, resellers, qualified consumers and external agents who are authorised to participate in the market by the Ministry of Industry and Energy. Buyers may present bids to purchase electricity on the daily market. However, in order to do so, they must be registered with the Administrative Register of Distributors, Resellers and Consumers and they must abide by the Electricity Market Activity Rules. A purchasing unit is deemed to refer to a group of network connection nodes through which the buyer presents bids to purchase electricity.

Sale and purchase bids can be made considering between 1 and 25 energy blocks in each hour, with power and prices offered in each block. In the case of sales, the bid price increases with the block number; in the case of purchases, the bid price decreases with the block number.

Electricity sale bids presented by sellers to the market operator may be simple or incorporate complex conditions in terms of their content. Sellers for each hour and production unit present simple bids, indicating a price and an amount of power. Complex bids are those that incorporate complex sale terms and conditions and those which, in compliance with the simple bid requirements, also include technical or economic conditions.

We will take as the agent a producer that carries out simple offerings without restrictions, the study of complex offerings with technical restrictions we postpone it for future studies.

The market operator matches electricity power pur-

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chase and sale bids by means of the simple matching method (Decree, 2000).

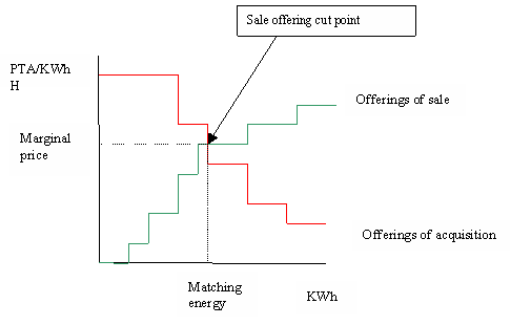

Figure 1: Procedure of Simple Matching.

The simple matching method 1 is the one that obtains in an independent way the price in each hourly period of programming, marginal price, as well as the volume of electric power that is accepted for each unit of production and acquisition for each hourly period of programming.

The hourly marginal price is the price that obtains as a result itself of the process of matches, and is equal to the price of the last offering of sale that has been necessary to assign to cover the demand. This price is the one that charge all the producers that have been matched and that pay all it consumers that have been matched. This price has hourly character (Low, 1997).

The necessary information for the participation of a session of the daily market is facilitated for the operator of the market and this is the following:

- The last forecast of demand.
- Information on available units.
- Maximum capacity in the interconnections.

The estimation of the demand is a daily evolution forecast of the periods hourly national consumption. This it is make public for all the agents of the market.

Several times of the day, the MO puts available information on the unavailable agents. This information is prominent since available every unit of output is obliged to present offering of daily market. An agent is unavailable when for some cause is incapable to generate energy by damages or another thing.

The capacity of interconnection in the borders with the different bordering countries is limited. Therefore it is necessary the knowledge of the so much, hourly maximum capacities of importing as of export, to avoid a net flow that exceed some of these limitations.

The variables that in a first study can be considered and besides they can influence in it takes of decisions of the agents at the moment of to carry out their offering of blocks of energy and price marginal they are the following:

- Marginal price of previous day hours.
- Minimum costs of agent production.
- Weather prediction.
- Demand prediction system.

In our method we will use the two firsts to see as the agents behavior are.

In principle since, an economic point of view the producer interests him to produce a minimum quantity to cover cost and it will offer to a price that generate him these incomes. It will offer other blocks of energy to an upper price so that the tendency of the sale curve rise and obtaining high marginal prices.

The next section explain the method that we use to model the sellers. In section 3 we apply our method to some sellers and we interpret the obtained results. Finally, the conclusions and futures works are shown in section. 4. This work begins to study the variables that can influence that an agent who takes part on the pool obtains a few major benefits being capable of interpreting the behavior of the market. For it, it's necessary to model an agent's sample to see if we find pattern in his behaviors.

2 OUR METHOD

To study the behavior of the sellers we propose a method based in fuzzy logic (Zadeh, 1965) and linguistic variables (Zadeh, 1975a; Zadeh, 1975b; Zadeh, 1975c). We obtain a linguistic fuzzy model of a seller agent to study its behavior. Our method needs the hour (h variable) and the hourly margined price at this time in the previous day (c_{t-1} variable). So, we use the hour to the one that bid block is offered and the hourly margined price of the previous day as input variables, and the output variable is a list formed by pairs like the following: *[amount of energy, price of energy]*. We use s and p variables to represent amount of energy and price of energy in this pair.

A set of examples with the values of the variables and a set of sort linguistic labels (Zadeh, 1975a; Zadeh, 1975b; Zadeh, 1975c) for some variables are needed to obtain the fuzzy model.

The set of examples, named E, is formed by elements with the following structure:

$e_i = (h_i, c_{t-1,i}, s_i, p_i)$

where h_i is an integer number that has values between 1 and 24 (the hours of the day), $c_{t-1,i}$ is a real number that is the hourly margined price at this time the previous day, s_i is the amount of offered power in this block, and finally, p_i is the sold price of this block of energy (s variable).

To simply the algorithm of our method we suppose that for each hour and day the examples of E are consecutive. We use three type of variables: linguistic, integer and real variables. The variable c_{t-1} takes integer values, p variable takes real values, and the variables h and c are linguistic variables. The linguistic labels of the linguistic variables are defined a priori, i. e., before our method is applied.

An ordered set of labels, named C, is defined for the c_{t-1} variable. Its structure is given by the following expression:

$$C = \{very\ low, low, few\ low, medium, low\ high, high, very\ high\}$$

Figure 2 shows the trapezoidal labels used for the c_{t-1} variable, where VL is '*very low*', L is '*low*', FL is '*few low*', MD is '*medium*', LH is '*low high*', H is '*high*' and VH is '*very high*'.

Figure 2: Ordered set of labels C for the c_{t-1} variable.

This linguistic variable is used to represent the hourly margined price at the previous day. We represent the price of sale of the energy with label by means of variables linguistic that mean the following:

'Very low' This label is used when the sale price is very cheap. It takes values between 0 and 1, and, normally, this label is not used in the daily market because this price is never obtained.

'Low' This label takes values between 0.75 and 2. When the energy is sold to this price, it is cheap. This sale price is frequently used from 3:00 or 4:00 until 5:00 or 6:00.

'Few low' This label takes values between 1.75 and 3. It is a sale price a little cheap, and it is a price frequently used during the day.

'Medium' This label takes values between 2.75 and 4. This is the normal sale price, and it is a price frequently used during the day.

'Low high' This label takes values between 3.75 and 5. Normally, from 8:00 or 9:00 to 22:00 or 23:00 the energy price is this or the next label.

'High' This label takes values between 4.75 and 6. Normally, from 8:00 or 9:00 to 22:00 or 23:00 the energy price is this or the previous label.

'Very high' This label takes values between 5.75 and 10. In the daily market this price is never obtained.

An ordered set of labels, named P, is defined for the p variable. Its structure is given by the following expression:

$$P = \{not\ important, very\ cheap, cheap, little\ cheap, norm, little\ expensive, expensive, more\ than\ expensive, very\ expensive\}$$

Figure 3 shows the trapezoidal labels used for the p_i variable, where NI is '*not important*', VC is '*very cheap*', C is '*cheap*', LC is '*little cheap*', NR is '*norm*', LE is '*little expensive*', E is '*expensive*', MTE is '*more than expensive*' and VE is '*very expensive*'.

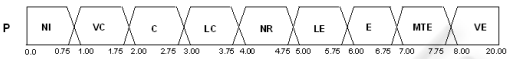

Figure 3: Ordered set of labels P for the p variable.

This linguistic variable is used to represent the offered price in each energy block. Every definite label means:

'Not important' This label is used when the hourly margined price is not important for the seller, that is, the seller wants to sell the energy block be which is the price. Normally, This label appears at least in some block offered by the producers. This label takes values from 0 to 1.

'Very cheap' This label takes values from 0.75 to 2. This label is used when the seller wants to sell the energy to a minimum price. The energy blocks to this price are frequently sold.

'Cheap' This label is used when the seller wants to sell the energy to a minimum price. The energy blocks to this price are frequently sold when the time is between 1:00 or 2:00 to 5:00 or 6:00. This label takes values from 1.75 to 3.

'Low cheap' This label takes values from 2.75 to 4. The energy blocks to this price are frequently sold when the time is between 20:00 or 21:00 to 24:00 or 1:00. This label is used to sell energy blocks at these times.

'Norm' or 'Few expensive' These labels are used when the energy market reaches the maximum price, that is, the hourly margined price is rarely more than 6. Normally, '*few expensive*' is the biggest label obtained in the daily energy market. When one productor seller sells energy to these prices, he wants to obtain a great benefit.

'Expensive' to 'Very expensive' These three labels rarely are obtained in the daily energy market. When a seller agent offers energy blocks to this price, he doesn't want these blocks, only if occurs a "special situation" like '*a powerful agent is damaged*', '*there is necessary a lot of energy*', etc.

The order of the labels in C and P is based on the defuzzification method named middle of maximum

(MOM) (W. V. Leekwijck, 1999). Our method obtains a system of fuzzy rules formed by rules with the following structure:

IF ($h\ is\ X$**) AND (**$c_{t-1}\ is\ C_i$**) THEN**
$[[s_1\ is\ S, p_1\ is\ P]$,
$[s_2\ is\ S, p_2\ is\ P]$,
...
$[s_n\ is\ S, p_n\ is\ P]]$

where X takes integer values, c_i is the linguistic variable that takes values from C, S is a real variable and P is the linguistic variable that takes values from P.

A real example of a rule obtained by using our method is the following:

IF (2**) AND (**'*Medium*'**) THEN**
$[[180,'\ not\ important']$,
$[50,'\ very\ cheap']$,
$[50,'\ cheap']$,
$[50,'\ cheap']$,
$[20, very\ expensive]]$

As you can see, the output of the rule is a list of pairs *[amount of energy, price of energy]*. Each pairs of the list understands it better because we use linguistic labels for the P variable. This rule can be interpreted as the following text:

"When the hourly margined price in the previous day is 'medium' and it is the second hour of the day, then the seller agent sells 180 energy units be which is the hourly margined price in the current day, 50 energy units when the energy is 'very cheap', two blocks of 50 energy units when the energy is 'cheap' and 20 energy units when the energy is 'very expensive'"

When we study the Spanish electric market, we observe that when the energy is *'very cheap'* or *'cheap'* it is very possible that the offered blocks at this price are sold, and when the energy is *'very expensive'* the offered blocks at this price are never sold. Thus, in this case, we can conclude that the productores seller wants to sell one block of 180 energy units and three blocks of 50 energy units because the offered energy has a null price in the first case and a price that it is very possible to sell in the second case; and it doesn't want to sell a block of 20 energy units because The block has a price at which the energy never sells.

Algorithm 1, it shows the code used to obtain the linguistic fuzzy model. As you can see, the algorithm has three inputs: the set of examples E, the ordered set of labels C and the ordered set of labels P. The output is a linguistic fuzzy model named M.

The idea of this algorithm is to be crossing the examples in E. To obtain the items that compound the antecedent (the hour and the hourly margined price); and the items that compound the consequent (a list of pairs like *[amount of energy, price of energy]*), for this purpose, some consecutive iterations of the **for** loop are used (so many iterations like energy blocks are offered for the hour that the rule represents). After that, the rule that represents this hour is calculated. This process is repeated while there is some example in E. As you can see, the algorithm obtains a rule for each hour.

INPUTS:
Set of examples E
Ordered set of labels C
Ordered set of labels P
OUTPUT:
A linguistic fuzzy model M
ALGORITHM 1:
1. $M =< >$
2. $C_{t-1} = ObtainLabel(c_{t-1,1}, C)$
3. $p = ObtainLabel(p_1, P)$
4. $Pairs = [\ [s_1, p]\ ]$
5. **for** $i = 2$ **to** $|E|$ **do**
6. **if** $h_i\ is\ equal\ to\ h_{i-1}$ **then**
7. $p = ObtainLabel(p_i, P)$
8. $Pairs = Pairs + [s_i, p]$
9. **else**
10. $R = CreateRule(h_{i-1}, C_{t-1}, Pairs)$
11. $M = AddRule(R)$
12. $C_{t-1} = ObtainLabel(c_{t-1,i}, C)$
13. $p = ObtainLabel(p_i, P)$
14. $[\ [s_i, p]\ ]$
15. **EndIf**
16. **EndFor**

Now, we show the behavior of the algorithm line to line. M is assigned to empty ($'< >'$) in the line 1. Line 2, we calculates the label C_{t-1}, for this purpose, it is used the following equation:

$$C_{t-1} = max_{C_w} \mu_{C_w}(c_{t-1,i}),\ \forall C_w \in C \quad (1)$$

That is, the label of C that has the maximum membership grade to $c_{t-1,i}$ of e_i.

Line 3 calculates the label p, for this purpose, it is used the following equation:

$$p = max_{P_w} \mu_{P_w}(pi),\ \forall P_w \in P \quad (2)$$

That is, the label of P that has the maximum membership grade to p_i of e_i.

In the algorithm, the list of pairs is denoted as *Pairs*. In line 4, the first pair *[amount of energy, price of energy]*), that represents the first offered block, is obtained and added to *Pairs*. Its first component is assigned to s_1, and the second one is the label p (calculated in line 3).

After that, a **for** loop is used to go through the examples in E pointed by the index i (line 5). The sentences of the **for** loop are the sentences in the lines from 6 to 16. If h_i is equal to h_{i-1}, it means that the

hour of the previous example is equal to the hour of the current example, that is, the examples i and $i-1$ represent energy blocks offered for the same time. In this case, the algorithm adds the new pair to the list of pairs *Pairs*. The sentences of the lines 7 and 8 are used for this purpose. The sentence in the line 7 calculate the label p to represent the offered price for the current block by using the equation 2. The sentence in the line 8 adds the pair to the list *Pairs*.

If h_i is not equal to h_{i-1}, it means that all consecutive energy blocks offered for the same day and hour has already been added to *Pairs*, thus, the rule that represents the hour h_{i-1} (R) is added to the model M (lines 10 and 11), and it is begun to calculate the rule that represent the hour h_i (lines 12, 13 and 14). The meaning of the lines from 10 to 14 are the following:

Line 10 The rule R is calculated by using the hour h_{i-1} and the label C_{t-1} (the label to represent the hourly margined price at h_{i-1} in the previous day) for the antecedent, and the list of pairs *Pairs* for the consequent.

Line 11 R is added to the model M.

Line 12 The label C_{t-1} is calculated by using the equation 1.

Line 13 The label p is calculated by using the equation 2.

Line 14 *Pairs* is initialized at $[\ [s_i, p]\ ]$

Finally, the last sentences close the **for** loop and the **if** sentence.

3 TESTING THE METHOD AND THE INTERPRETATION OF THE OBTAINED RESULTS

We apply the proposed method to the data of three seller agents in the first five days of the month of June of 2003 to test our method. The producing agents are named $ABO1$, $ALL1$ and $VIES$.

Our method obtains 24 rules for each day (one rule for each hour of the day), so, the obtained models for these 5 days are formed by 120 rules. For each hour, our method obtains 5 rules, one rule for each day.

Now, we explain the interpretation of the obtain model for each one of the producing agents:

$ABO1$ This agent maintains the sold energy at 350 energy units during all hour of the day, although it changes some energy unit from a block to another block hour at hour. It can be observed that the night hours the energy offered is smaller than the day hours. It carries out three types of offered blocks: a first block to prices qualified with the label *Not Important* is offered so that enter the matches; three blocks to prices with labels qualified among *''very cheap*' or '*cheap*' are offered so that it wants a minimum value in the matches; and a last energy block, labeled as *''very expensive*', it is offered to a price that the energy market has never obtained. Thus, we can conclude that this agent offers three set of blocks: a first one that it will always be accepted; a second one that it will be accepted when a minimum price has been gotten; and a third one that it will never be accepted.

$ALL1$ This agent maintains the sold energy at 364.9 energy units during all hour of the day, although it changes some energy unit from a block to another block. It can be observed that the night hours the energy offered is smaller than the day hours. It carries out three types of offered blocks: a first block to prices qualified with the label *Not Important*; others blocks to prices with labels qualified among *'very cheap*'; and a last energy block, labeled as *'very expensive*'. From 8:00 or 9:00 until 23:00 or 24:00, this agent only offers the following two blocks: *[335.0, 'not important'], [11.9, 'very expensive']*, that is, during these times, 335 energy units will always be accepted and 11.9 energy units will never be accepted. Thus, we can conclude that this agent offers three set of blocks: a first one that will always be accepted; a second one that will be accepted when a minimum price has been gotten; and a third one that will never be accepted.

$VIES$ This agent do not maintains the sold energy at a constant number of energy units during all day. It only offers the energy units that want sell to prices qualified with the label *Not Important*. It can be observed that the night hours the energy offered is smaller than from the day hours. We can conclude that this agent offers only the energy units that want sell, for this purpose, it labels to '*not important*' the only block that it offers.

As behavior common to all the studied agents, we can say the following:

1. The hourly margined price is similar at the same hour of the consecutive days.
2. All studied agents bids each days the same number of blocks at the same hour. The amount of energy is very similar for the same hour at different days.
3. The first blocks to prices qualified with the label *not Important* are offered so that enter the matches.
4. Blocks to prices with labels qualified among *very cheap*or *cheap* are offered to obtain a minimum price.
5. The tendency is that the last blocks have some prices qualified with labels of *expensive* or *very expensive*.

6. Along the day, the agents change the amount of energy from blocks labeled with labels not equal to '*not important*' to the block labeled with labels equal to '*not important*'.
7. The agents doesn't study the offered energy blocks in detail. They present similar offers hour at hour.

A situation is described in which the agents always offer a minimum to function in each hour to price *'not important'*. From this point different tendencies are seen, there are agents that directly offer blocks to prices that in the historic one of marginal prices never they have been reached, this signifies that they do not enter the matches, and other they offer to prices that are going to enter. We interpret it since really the agents have to maintain a most minimum operation by technical restrictions of the head offices for that reason be offered to *'not important'*. The behavior is different from here but is seen that there is not a tendency to adjust the offering to the marginal price that have greater possibilities to be. This due to that itself not a study of forecast of the marginal price is done. Also due to that the agents try with these high prices in the last blocks to rise the tendency of the curve and consequently to rise the point of cut of the curves of sale and purchase.

4 CONCLUSIONS AND FUTURE WORKS

For the first time methods of fuzzy logic are in use for interpreting the behavior of the producing agents by means of a system of fuzzy rules that they allow us to visualize better like it organizes his production throughout the day, hereby the decisions will be able to be analyzed better to taking. We can conclude of the carried out studies that the agents maintains the sold energy units during all hour of the day, although it changes some energy unit from a block to another block hour at hour. As we thought, the energy uses in the night is cheaper than the energy in the day hours.

The agents offer set of energy blocks with different purpose. The first set is offered to produce a minimum quantity to cover cost and it will offer to a price that generate him these incomes. Other set of blocks are offered to sell energy when the hourly margined price has a minimum value. These blocks permit to the seller agent to obtain benefits. It offers other blocks of energy to an upper price so that the tendency of the sale curve rise and obtaining high marginal prices.

The agents doesn't study the offered energy blocks in detail. They present similar offers hour after hour and day after day.

As future works, we can apply the presented method but using another variables like the last forecast of demand, information on available units, minimum costs of agent production, weather prediction or demand prediction system. A seller agent can be considered as a "cyclical dynamic systems" (day after day). We can apply fuzzy technics that model dynamic systems like (J. Moreno-Garcia, 2003a) and (J. Moreno-Garcia, 2003b).

Seems clear that the model of agents is different and differs depending on the volume of production or sale of the agent. We should deepen in the analysis of the market that permit us by means of temporary systems of analysis to predict the marginal price of the next day.

In this manner we would be able model the agent so that we will use this value as entrance in his system of offerings.

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