DGENCO Market Balancing – Cost repartition under Light Regulation Markets

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Abstract — **In this paper we present a new methodology, based in game theory, to obtain the market balancing between Distribution Generation Companies (DGENCO), in liberalized electricity markets. The new contribution of this methodology is the verification of the participation rate of each agent based in Nucléolo Balancing and in Shapley Value. To validate the results we use the Zaragoza Distribution Network with 42 Bus and 5 DGENCO.**

I. Introduction

The deregulation of the electrical business on a global scale tries as final target the rationalization of the energy prices, establishing an market environmental by means of the desverticalization of the companies in four fundamental activities: generation, transmission, distribution and commercialization.

The remuneration of the generation and commercialization activities are established according to a market structure and the transmission and distribution activities are considered to be natural monopolies. In the worldwide experience an increasing opening of the market has happened in the activity of generation. Nevertheless, the introduction of the consumption as market agent is a process in slow and in development.

In many countries, the activities of commercialization and distribution are concentrated even on the traditional companies of service that take part of the wholesale market and that attend to the captive users without choice possibility. In a theoretical context of soft regulation, in these distribution/commercialization's companies can fix prices and the regulator watches his grade of benefit, it is feasible to obtain a market balance in which every company tries to maximize its own benefits.

The study of the remuneration and the prices establishment, by means of the application of skills of market balance presents itself here as a possible alternative to the classic remuneration scheme of the monopolies based on the minimal social cost.

In this paper, we present a methodology based on the Game Theory for the securing of the market balance between distribution/commercialization companies with captive consumers who answer elastically with the energy price. Like original contribution, there decides the grade of participation of every agent by means of the Nucléolo balancing and the Shapley Value. A 42 bus distribution system has been used with the participation of up to 5 companies.

II. Light Regulation Model

The distribution and marketing has traditionally been regulated under the scheme of service pay the cost of recognizing in the adequate rate of return (*Cost of Service / Rate of Return CoS / ROR*). In this scheme the activity is considered a natural monopoly and the rates are set by the regulator. New approaches driven by the increasing liberalization of the electricity sector have led many countries to implement new schemes for incentive-based regulation (*Performance Base Ratemaking or PBR*) such as price caps (*Price Cap*), the limitation of revenue (*Revenue Caps*) or regulation by comparison (*Benchmark or yardstick competition*). This type of regulation continues to recognize the distribution as a natural monopoly and therefore, consumers should be protected from any abuse of the carrier affects the end price of energy. Regulatory incentives aimed at limiting the income of the monopolist forcing a strategy to reduce costs to get the most benefit. Based on the results, the compensation can be enlarged or reduced in order to encourage efficiency [7].

However, in the last stage of the liberalization process, marketing is an activity open to competition and consumers become active agents of the market. In this regard, regulation of public utilities now be considered a regulation of transport activity, governed by a monopolist and paid based on the tariffs for network use. In this context, some authors [8] have proposed a scheme of *soft regulation*, in which the marketer sets prices and consumer prices respond elastically to such established market equilibrium or simply switching to another supplier.

However, despite being available choice of supplier, in practice there is no such capability exists in a unique geographical distribution and marketing company, which although being legally separate answer to the same shareholders and act as a sole distributor - trading.

In this context, this paper proposes a method to evaluate the market equilibrium between coalitions of various distribution and marketing companies with different geographical concessions, with captive customers Disability alternative provider of choice.

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III. Prices Formulation Model

The model for the prices formation used in this work is based on the presented one on [1] using as objective function the proper company benefit and subjected to the technical restrictions of the distribution network.

This model supposes the same price for all the network users (uniform and not discriminatory price). Moreover, the consumer is adapted to a competitive environmental since he knows the variable behavior of the tariffs in a daily period and consequently, it acts instantaneously for changing his consumption depending on the utility that provides to him the energy at certain hour of the day.

From the point of view of the distribution company, the raised problem is to obtain the prices that maximize his own benefit. There is defined the benefit of the company as the difference between the income and the costs. The income is the product of the energy, it demands for the consumers and the price, and the costs corresponding to the costs of distribution, commercialization, reliability and the acquisition of the energy on the market. In general form the model of maximization of the benefit of the company can be written for any hour h, as following:

$$max \sum_{i=1}^{N} \rho P_{Sih} - C_{FIJOh} \quad (1)$$

Subject to:

$$P_{Ljh} = P_{Sih} + K_j \cdot P_{Ljh} + \sum_{m\in C(j)} P_{Lmh} \qquad i = 1,....,N \quad (2)$$

$$Q_{Ljh} = Q_{Sih} + K_j \cdot Q_{Ljh} + \sum_{m\in C(i)} Q_{Lmh} \qquad i = 1,....,N \quad (3)$$

$$(P_{Ljh})^2 + (Q_{Ljh})^2 \le (S_{Ljh}^{\max})^2 \qquad j = 1,....,N-1 \quad (4)$$

$$Q_{Sih} = P_{Sih} \tan\varphi_i \qquad i = 1,....,N \quad (5)$$

The terms *Ps* and *PL* possess energy units, as soon as that the developed model uses a temporary hourly period, corresponding in this case to the consumption of kW in an hour, that is to say kWh.

The constraint corresponding to the balance of active power and it reactivates from the system, to the maximum permissible power flow and to the power factor concentrated on every node. To obtain the power balance, a simple impedance model has been used (seeFigure 1). The losses are linearized based on the concept of the economic current density [9]

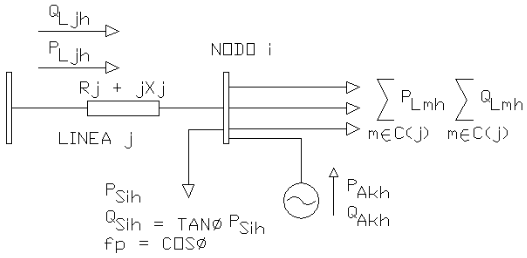

Fig. 1. Line Model

The consumer model is introduced by a linear function in each node:

$$P_{Sih} = A_{ih} \cdot \rho_h + B_{ih} \qquad i=1...N \quad (6)$$

For the 24 hour prices formulation does only one problem of optimization appear with an hourly price? h, h=1..., 24. The objective function for 24 hours performs aquadratic expression as:

$$[\sum_{h=1}^{24}\sum_{i=1}^{N}(A_{ih}\rho_h^2 + B_{ih}\rho_h)] - \{[C_{D+C} \cdot \sum_{h=1}^{24}\sum_{i=1}^{N} P_{Sih}] + [\sum_{h=1}^{24}\rho_{mh}P_{mh}] + [C_T \cdot \sum_{h=1}^{24} P_{mh}] + [C_F \cdot \sum_{h=1}^{24}\sum_{i=1}^{N} \lambda_i \cdot r_i \cdot P_{Sih}]\} \quad (7)$$

The nature of the problem is a quadratic programming and for its solution the ~~Excell~~Excel Solver has been used .

IV. Game Theory

The Game Theory is a discipline used to analyze problems of conflict between two agents that take decisions. It can be considered to be a generalization of the theory of decisions to include multiple players [2]. The Game Theory is a type of mathematical analysis faced to predicting what will be the true result or the most probable result of a dispute between two individuals [3].

3.1 Game

A game is a process in which two or more persons (named players), take decisions and realize actions, under a structure that is inscribed in a set of rules (that can be formal or informal), at the end of obtaining benefit [3].

It corresponds to every entity qualified to take decisions in autonomous form about the base of an unitary interest, they can be for example, generating, consuming, etc. For every game a finite number of players [4] are assumed. The conduct of every player, it will have to be typified, so that it could be known of what probable or true form he will behave, under the premise of which every player will look for his maximum possible well-being.

Thus, having analyzed the behavior of a player, we will know that this one will have to qualify every situation and always chase the particular situations that offer the biggest well-being [3]. The solution of a game is the combination of profit or losses that gives the game with certainty or with high probability to the players. If the game is supreme zero, which they gain some it lose others.

When the game is supreme non-zero, there is denoted the value of the game as the combination of the profit that the game gives, once decisively, to the players [3].

3.2 non-cooperative games

Part of that players not cooperate and seek to maximize their individual benefits, and it is the right choice in the study of situations associated with competition [4].

3.3 Cooperative Games

Part of that players are grouped together and cooperate in order to seek equity and welfare, and therefore the best option for the costs allocation [4].

3.4 Development of an application of game theory

To use game theory for a real situation, we need to construct simplified models of reality. In these models, you will need to properly represent each player with their respective forms of conduct. Such conduct can be known with certainty, or only as probable (stochastic). You may be required to raise two or more representations of the probable behavior of the players, each of these representations stage. Each scenario is a simple game. The set of two or more settings comprises a game [3].

3.5 Coalitions

Generally, the players are grouped into coalitions in order to obtain greater profits than if they act separately, so there in a game several coalitions, including us:

- Individual: formed by a single player
- Empty: no players
- Grand coalition: formed by all players in the game

It is assumed that coalitions are mutually exclusive and exclusionary, i.e. the formation of a coalition means that each of the players will agree that a player can not join a coalition of more than [4]. The structure of the coalition is described as the players are grouped into coalitions in a game:

$$\delta = \{S_1, S_2, S_3, ..., S_m\} \tag{8}$$

Where δ is the structure of coalitions of a game and Coalitions If a mutually exclusive and extaxpayers. For a game of n players coalitions exist 2n possible [4]. The formation of coalitions is a process in which alliances are made between groups of participants who are seeking to increase their profit. In [5] describes an algorithm for the cooperative recognition process consists of four phases:

3.6 Step to obtain local information

Each agent gets its own information, for example, the cost or profit generation of electric energy consumption and identifies the benefit when acting alone. This benefit is called the eigenvalue of the agent, and will be the minimum value that the agent could achieve without cooperation with others.

Phase of communication

The communication between agents allows them to locate other agents with whom business can benefit if they cooperate. During this phase, each agent exchanges information that have been obtained previously, including their own with other agents, directly or indirectly through a coordinator. It also obtains information from the operator of the system on the environment surrounding the actors. The information exchanged between the players should be sufficient for the calculation of payments to unions.

Local phase calculation

Once each agent received information from other players, start calculating the local phase. Here, each agent calculates the profit sharing would gain from working alongside others and creates an order of preference for coalitions. The field of game theory offers several options for dividing the utility of the coalition between the actors involved in it.

Bilateral negotiation

At this stage, each agent maintains a list of preference of those with whom you can work together beneficially. The offerings extend to other agents according to their list of preferences, accept those that enhance their benefit and reject others that are not profitable. The newly formed coalition, it becomes a decision, i.e., a new agent.

The four steps above are iterative, it is not possible to build more coalitions, or until it reaches a preset limit. Each player has a payment or allowance x_i. The set of all payments are expressed as a vector of payments or function [4]:

$$\bar{x} = [x_1, x_2, x_3, x_4, ..., x_n] \tag{9}$$

A cooperative game of N players can be defined by a pair (N, c), where N is the set of players (A, B.., N) c being a real function defined for subsets of N and that called characteristic function of the game, it assigns a value c (Si) If each coalition. For the case of two players will have:

$$\{0, c(0)\}, \{A, c(A)\}, \{B, c(B)\}, \{AB, c(AB)\} \tag{10}$$

From the characteristic function, defined as follows:

Symmetry: Two players, A and B are symmetric if for all coalitions in which they can participate is met: such that

$$c(S \cup \{A\}) = c(S \cup \{B\})\ \forall S \subset N \quad A, B \notin S \tag{11}$$

Attractively: One player, A, is more desirable than another player, B if it satisfies: such that

$$c(S \cup \{A\}) \le c(S \cup \{B\})\ \forall S \subset N \quad A, B \notin S \tag{12}$$

Sub- additionally: This principle states that the value of a coalition or coalitions must be separated by a maximum equal to the sum of their individual values.

$$c(S \cup T) \le c(S) + c(T) \tag{13}$$

Monotheism: The costs of a coalition to continue or increase as more players are added to a coalition.

$$c(S) \le c(S + \{A\}) \tag{14}$$

Non-essential game: A game is not essential when there are no incentives to form coalitions, i.e.:

$$c(S \cup T) = c(S) + c(T) \quad (15)$$

The configuration of payments is the result of the game; it is formed by the vector of payments, cash costs for each player, and the structure under which the coalition was the solution.

$$(x, \delta) = (x_A, x_B, .., x_N, S_1, .., S_M) \quad n \geq M \quad (16)$$

The area or region defined by inequalities of the coalition and individual rationality and collective rationality of the equation are the core of the game. A game without a core is that it is not possible to find a set of payments to keep all players happy (satisfy) as at least one coalition will not. From the heart, as a first solution of the game, it is feasible to obtain stable solutions as a whole, whole negotiable, Kernel and Nucleoli (theory of excess), Shapley value, etc., The present work will explore only two of them, nucleolus and Shapley value [4].

V. Problem Planning

4.1 Nucléolo Balancing

The Nucléolo can be obtained from the determination of the excess. The excess is defined and as a measurement of dissatisfaction of a coalition with regard to a certain comparison of costs, then the Nucleolo contains the configurations of payments that minimize this dissatisfaction between all the coalitions. Thus, it can be stated as a linear programming optimization problem:

$$\max e \quad (17)$$

subject to:

$$c(S) - x(S) \geq e \quad (18)$$

$$x(N) = c(N) \quad (19)$$

4.2 Shapley Value

It is an evaluation to priori of every player who plays a game defined as a characteristic function *c* and any structure of coalition *S* [4]. For any typical function there will exist a vector of the only payment $\phi = (\phi_1, \phi_2, \phi_3, ...\phi_n)$ that expires with the following axioms:

Axiom 1, Symmetry: The value of the game of a player does not depend on the designation or name of the players, that is to say, the symmetrical players will have the same value.

Axiom 2, Optimality Pareto and efficiency: The sum of the values of every coalition in every coalition:

$$\sum \phi_i = c(N) \quad (20)$$

Axiom 3, void Player: If the player A is void $c(S) = c(S - \{A\})$, in this case $\phi_A = 0$.

Axiom 4, Additively: The value of the sum of two games is the sum of the values of the games. If the Value Shapley for a game *v* is *x* and for a game *v´* it is and, the vector of payment of Shapley for a game (*v*+*v´*) will be *x*+*y*.

If theses four axioms are fulfilled earlier special, will the only function exist, ϕ, called Shapley Value, whose components for the big coalition of a game will be determined for:

$$\phi_i = \sum_{S \in N} \frac{(n - S)!(S - 1)!}{n!} [c(S) - c(S - \{i\})] \qquad i \in N \quad (21)$$

To realize the analysis of the companies on a deregulated competitive market, the model developed in [1] was conditioned to allow the allocation to every company of a group of distribution nodes.

To effects of this work, it was considered that in this distribution network, they can operate up to five companies, this way, to assign to him, every node the number that identifies every company. The resolution of the problems of optimization does of form iterative up to completing them *2n* possible combinations, being n the number of companies that operate in the distribution network. For this, a developed tool in Visual Basic for applications in Excel has performed, in which there is obtained each of the combinations given by all the possible coalitions, and one to one is solving the problem of calculation of tariffs and benefit for a company composed by the market of the coalition.

VI. Case Study

The proposed methodology has been applied to a real distribution l network which consumers were connected to the 42 buses and who are a part of the market of one of 5 companies that operate geographically differentiated in the zone, as it is established in the Table 1 and Fig. 2.

Table 1. Distribution Network Market

Distribution Company	Buses
A	1-8
B	9-16
C	17-24
D	25-32
E	33-42

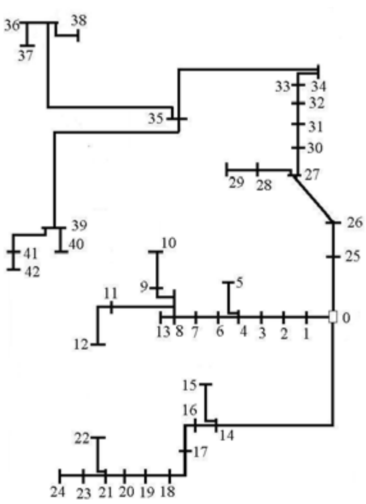

Fig. 2. 42 Bus Distribution network

6.1 Entire benefit for coalition

Table 2, shows the results of the entire benefit corresponding to five companies and all the possible coalitions.

Table 2. Entire benefit for coalition

Company	TOTAL	Company	TOTAL
0	0.00	E	367,030.00
A	298,067.59	EA	665,087.88
B	231,004.80	EB	595,973.85
BA	526,917.40	EBA	893,342.95
C	149,917.34	EC	503,585.67
CA	435,267.99	ECA	797,930.55
CB	376,523.34	ECB	734,566.14
CBA	666,142.64	ECBA	1,028,779.33
D	232,049.95	ED	597,106.74
DA	528,041.34	EDA	894,497.59
DB	463,055.04	EDB	827,291.04
DBA	758,301.95	EDBA	1,124,020.41
DC	377,466.72	EDC	735,608.80
DCA	667,172.18	EDCA	1,029,859.78
DCB	607,039.15	EDCB	966,601.52
DCBA	898,115.99	EDCBA	1,260,761.27

Table 3 shows the values of the benefit (the maximum individual benefits show themselves hatchings). These values are obtained for the studied case and it is possible to observe the strategies that will be adopted to each distribution companies.

The mentioned results can face the decisions of the companies of the following form: the company A, C and E, being rational in the capture of decisions, they will choose the option to operate alone, trying to supply of a large consumers. On the other hand, the companies B and D, they coincide with the strategy of forming a coalition, which will bring a major benefit in contrast to if they operate alone.

Table 3. Allocation of Cost Benefits

Empresa	A		B		C		D		E	
Coalición	V. S.	Nuc	V. S.	Nuc	V. S.	Nuc	V. S.	Nuc	V. S.	Nuc
0	0	0	0	0	0	0	0	0	0	0
A	298.07	298.07	0	0	0	0	0	0	0	0
B	0	0	231.00	231.00	0	0	0	0	0	0
BA	296.99	296.99	229.93	229.93	0	0	0	0	0	0
C	0	0	0	0	149.92	149.92	0	0	0	0
CA	291.71	291.71	0	0	143.56	143.56	0	0	0	0
CB	0	0	228.81	228.81	147.72	147.72	0	0	0	0
CBA	292.77	295.91	229.87	230.94	143.50	139.29	0	0	0	0
D	0	0	0	0	0	0	232.05	232.05	0	0
DA	297.03	297.03	0	0	0	0	231.01	231.01	0	0
DB	0	0	231.00	231.01	0	0	232.05	232.05	0	0
DBA	296.42	295.91	230.40	230.67	0	0	231.48	231.72	0	0
DC	0	0	0	0	147.67	147.67	229.80	229.80	0	0
DCA	292.81	289.78	0	0	143.45	145.42	230.91	231.98	0	0
DCB	0	0	229.79	230.29	146.46	145.52	230.79	231.23	0	0
DCBA	293.27	295.91	230.25	230.94	143.31	139.29	231.29	231.98	0	0
E	0	0	0	0	0	0	0	0	367.03	367.03
EA	298.06	298.06	0	0	0	0	0	0	367.03	367.03
EB	0	0	229.97	229.97	0	0	0	0	366.00	366.00
EBA	297.47	297.67	229.39	228.94	0	0	0	0	366.48	366.73
EC	0	0	0	0	143.24	143.24	0	0	360.35	360.35
ECA	294.71	296.21	0	0	139.88	137.20	0	0	363.35	364.52
ECB	0	0	229.92	230.99	143.18	145.52	0	0	361.46	358.06
ECBA	294.79	295.91	230.01	230.14	140.50	137.75	0	0	363.48	364.97
ED	0	0	0	0	0	0	231.06	231.06	366.04	366.04
EDA	297.49	297.68	0	0	0	0	230.49	230.08	366.51	366.74
EDB	0	0	230.39	230.64	0	0	231.48	231.68	365.43	364.97
EDBA	297.03	296.00	229.92	230.92	0	0	231.03	232.05	366.03	365.05
EDC	0	0	0	0	143.14	145.42	230.96	232.04	361.51	358.16
EDCA	294.82	295.99	0	0	140.46	138.39	231.07	231.17	363.51	364.31
EDCB	0	0	230.27	230.99	143.02	145.42	231.32	232.04	361.99	358.16
EDCBA	294.81	295.28	230.27	230.97	140.80	139.81	231.34	232.02	363.53	362.68

In this case, the strategy of operating together turns into a better strategy, since the companies that form the coalition choose the same strategy for different circumstances faced by the player (strategies of the coalition opponent) [6].

With this methodology, the companies they can as soon as the maximum benefit was determined locate the strategy of hourly tariffs that produces to him this maximum benefit.

Thus, the companies can be provided with a tool that allows to evaluate the different strategies of the game represented by the network operation and to determine the option that allows him to increase his benefit.

VII. Conclusions

Due to the social importance that has the electricity, it is important to develop methodologies for the establishment of suitable tariffs, which allow so much a reasonable yield of the company and the viability of the necessary investments to support the service quality levels, as well as also, allow the user to pay a just identical price to the quality of the service that it receives. In ambiences of competition, the Game Theory provides of hardware of big scope that they allow to evaluate and to take decisions about the several strategies that appear with the interaction of several companies that operate in an electrical system. Each of these alternatives represents possible stages, and methods as the applied ones must be used, to determine the maximum benefit and in which of the options this maximum happens.

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