Implementation of competition in the electricity market

Onja Voalintsoa[1]

[1] Assistant lecturer, Ecole Doctorale Science et Technique de l'Ingénierie et de l'Innovation, University of Antananarivo, Antananarivo, Madagascar

ABSTRACT

The economic modeling of the electricity market is done first by studying the supply and demand of the market from which the equilibrium and the logic of the agents have been obtained. Electricity market competition has been modeled according to Cournot, Bertrand and Stackelberg. Possible strategies for opening up a market have resulted in planning models for the electricity market. The implementation of competition in the electricity market continues with the distribution of future production, by the Cournot-Nash equilibrium, after knowledge of the distribution of powers in an electrical energy network.

Keywords: *electricity market, competition, planning, game theory, oligopoly*

1. INTRODUCTION

The electricity market is presented as an energy market, the majority share belongs to the state. More generally, electricity cannot be stored so it must be available according to demand: which differentiates it from other products for sale. The electricity network is made up of a set of works for the production, transmission and distribution of electrical energy. To ensure its stability, we must balance production and consumption at all times through real-time management of the electrical system.

1.1 Generality of the electricity market

The electricity market is organized around four major poles: generation, transmission, distribution, and marketing. Each of these poles corresponds to a specific activity for supplying consumers with electricity [1]. In real-time management of an electrical system, production and consumption must balance each other at all times, otherwise there will be a generalized electrical incident. To achieve this balance, while minimizing costs, managers use the means at their disposal, starting with the least expensive towards the most expensive, or they can also exchange production capacities. Given the large cost difference between the means of production, and this constraint of equilibrium at "any price", the resulting price of electricity varies enormously over time, especially between periods of low and high consumption [2]. For more than a decade, the policy change has led to the liberalization of electricity markets. The objective of this liberalization is the creation of an internal market which offers customers security of supply, as well as competitive prices and services.

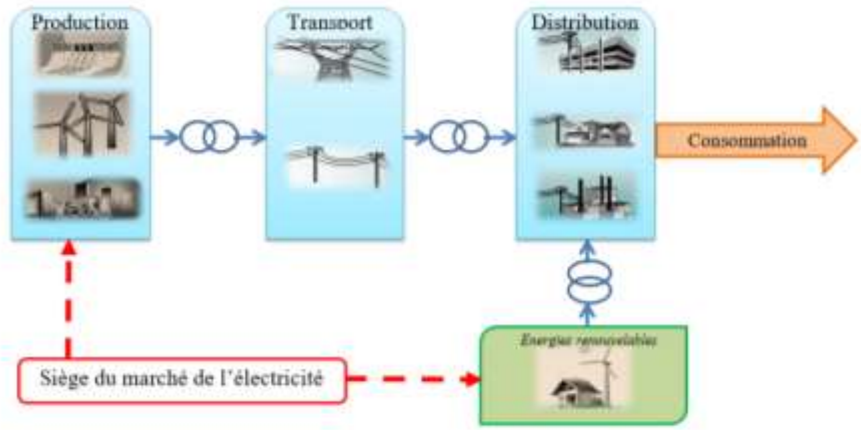

Fig -1: Electricity market place by route of electric energy

1.2 Opening up the electricity market to competition

There is no real common energy policy but a competition policy applied to energy and a minimum set of concerns common to all members based on three pillars: security, competitiveness, sustainability. The principle is to open up network industries to competition by separating regulated and unregulated activities. [3]

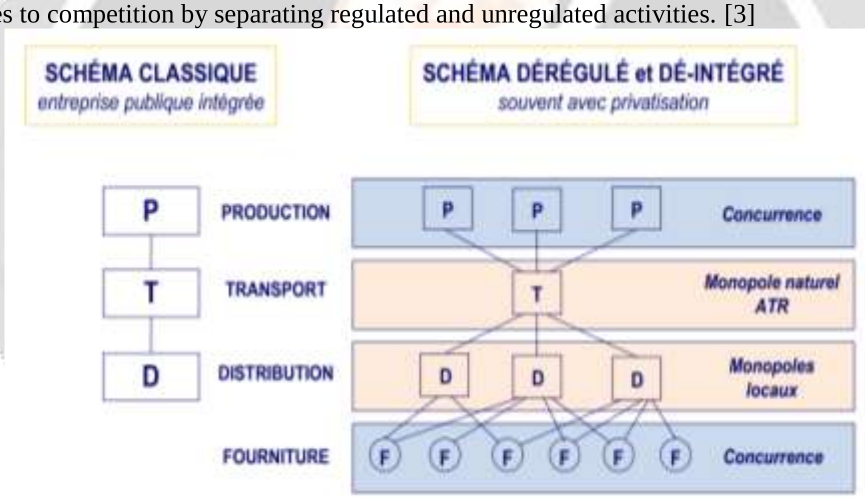

Fig -2: Opening up to competition

2. ECONOMIC MODELING OF THE ELECTRICITY MARKET

Knowing the structure and forms / reforms of the electricity market, let's model this market economically, taking into account its principles according to its actors. By the details of possible strategies for opening a market, we identify what corresponds to the electricity market with planning models. The manifesto of competition in the electricity market chronicles the workings of oligopolistic industries and the competing theories applied.

2.1 Market standard

A market evolves towards its equilibrium for these following reasons [4]:
(1) Prices regulate buying and selling intentions;
(2) When the buying and selling intentions do not match, the price will adjust.
In equilibrium, supply and demand determine an equilibrium price and an equilibrium quantity.
The competitive equilibrium must be found at the point of intersection of the supply and demand curves.

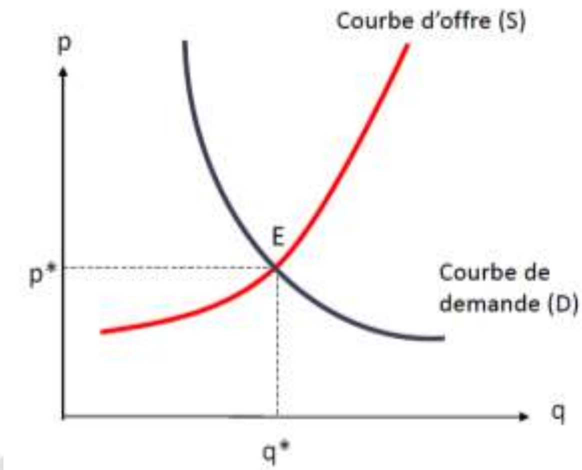

Fig -3: Balance of supply and demand

It is at the price $p<p^*$, the demand is q_D and the supply is q_S: all the demand is not satisfied hence there is excess demand.

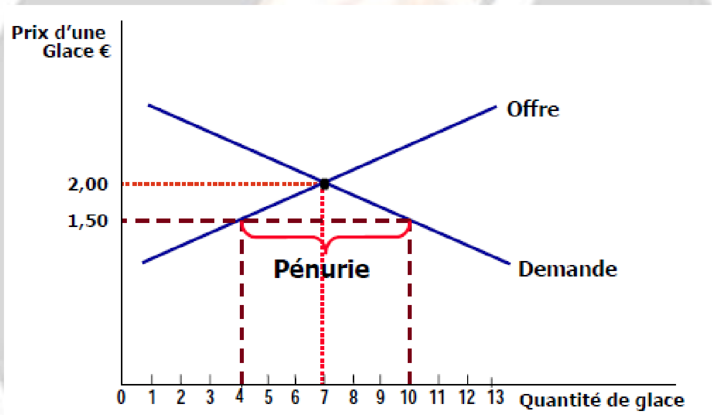

Fig -4: Example of excess demand

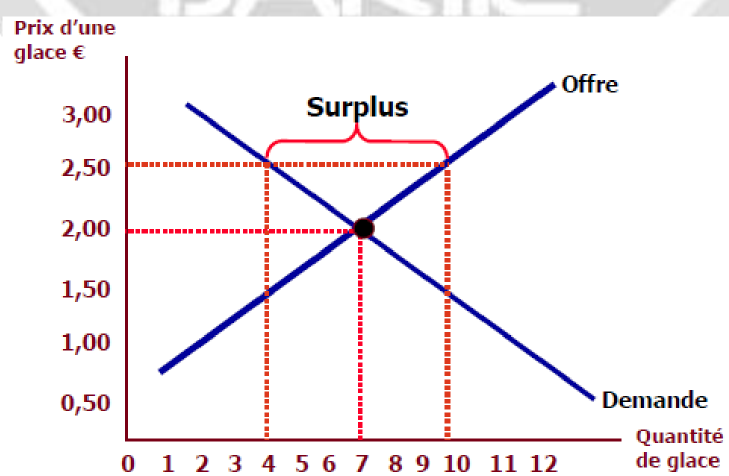

Fig -5: Example of excess supply

2.2 Economic models

Three main models generally illustrate the economic models of the competition [5]:
• Cournot model: competition on quantities, simultaneous play;
• Bertrand model: price competition, simultaneous play;
• Stackelberg model: competition on quantities, game in two stages.

Cournot's model considers two producers offering a product of equal (homogeneous) quality in the same competitive market. The proof of the existence of a Cournot equilibrium requires the following assumptions:
• The selling price of all producers in the oligopoly is the same:

$$C_i(q_i) = c_i q_i \qquad \text{with } c_i \geq 0$$

• Each player considers that the production of the others will not be modified by his production decisions, hence the profit function of firm i:

$$\pi_i(q_1, q_2) = p(q_1 + q_2)q_i - C_i(q_i)$$

$$q_{\neq i} = constante$$

• Each considers that he can act as a monopoly on the part of the demand that the others leave him: a small monopoly:

$$p(Q) = a - bQ$$

$$Q = \sum q_i$$

Suppose for n firms, each firm maximizes its profits such that:

$$\pi_i(q_1, q_2, \dots, q_n) = p(Q)q_i - C_i(q_i)$$

$$= \left[a - b\left(\sum_{j=1}^{n} q_j\right) - c_i\right] q_i$$

In Bertrand competition with homogeneous goods and identical and constant marginal costs, firms make no profit and offer an equilibrium price which is equal to marginal cost: Bertrand paradox.

$$\pi_i(p_i, p_j) = \begin{cases} D_i(p_i)(p_i - c_i) & si \quad p_i < p_j \\ \frac{1}{2} D(p_i)(p_i - c_i) & si \quad p_i = p_j = p \\ 0 & si \quad p_i > p_j \end{cases}$$

Based on Cournot's assumptions, Stackelberg imagines that one of the firms is able to guess how others will react to its actions. It knows the functions of reactions, and derives additional benefits from this knowledge. In fact, a producer plays the role of leader and announces his level of production before the rest of the producers, called followers, who take it into account in determining his own production. The followers are “Cournot-style” firms.

$$\pi_i(p_i, p_j) = q_i\, p\big(q_i + R_j(q_i) - c_i q_i\big)$$

Stackelberg has been able to make greater use of strategic interaction, in its understanding of oligopoly markets.

2.3 Manifesto of competition in the electricity market

For a simplistic model of a competitive electricity market, taking into account:
• atomicity: a price competitive with the Bertrand model;

• the homogeneity of the products: consider the active power produced with the Cournot model;
• free entry and exit to the market: rational producers with a Nash equilibrium;
• free movement of factors of production: no restrictions on trade with the Cournot - Nash equilibrium;
• transparency of information: investment planning in production with the uncertainties of several producers.

Firms compete with each other on price; each seeks to maximize its profit through its price. The choice of each firm i therefore arises by:

$$\max_{p_i}(p_i, c_i)\, D_i(p)$$

Companies choose their production capacities, anticipating the price competition that will take place later. Knowing that each unit of capacity costs c to build, we must subtract the amount ck_i from the previous profits, and we obtain the following profit function as a function of the capacities:

$$\pi_i(k_i, k_{-i}) = \begin{cases} -ck_i & si\ k_i \geq a/b \\ \dfrac{(a - bk_{-i})^2}{(4b)} - ck_i & si\ a/(3b) \leq k_i < a/b \\ \big(a - b(k_i + k_{-i})\big)k_i - ck_i & si\ 0 < k_i < a/(3b) \end{cases}$$

Consider any region which is electrified by several power plants, which offer the same service for a homogeneous market. The annual gain for each company depends on the amount of consumer demand D_i (s_i); and the total annual cost of the entire plant depends solely on its strategy profile *s*, *C(s)*. It is always trying to maximize her profit, let's assume we are on the rational side:

$$\max_{q_i} \pi_i(Q)$$

$$\pi_i = q_i[p(Q) - c] = q_i p - c_i(q_i)$$

The Cournot equilibrium is a Nash equilibrium in quantities. Each seller agrees to supply a given quantity at the price that will be established in the market.

Companies compete in research and development so as to lower their unit cost of production. We are therefore looking for a Nash equilibrium in innovation, that is to say a couple of innovation efforts $(x_1^n, x_2^n, \dots, x_n^n)$ such as:

$$\overline{\Pi}_i(x_i^n, x_{-i}^n) \geq \overline{\Pi}_i(x_i, x_{-i}^n)$$

$$\forall x_i,\ \ i \in \{1,2,\dots,n\}$$

In the case of research competition, each firm maximizes its individual profit. The marginal profit associated with an additional unit of innovation is equal to:

$$\frac{\partial \overline{\Pi}_i}{\partial x_i} = \frac{2}{9b}(2 - \psi)(a - c + (2 - \psi)x_i + (2\psi - 1)x_{-i}) - \gamma x_i$$

We consider n firms competing on m markets. We denote by q_{ij} the quantity that the producer i∈ {1,…, n} intends for the market j∈ {1,…, m}. The price p_j on each market is a linear and decreasing function of the total quantity offered:

$$p_j = a_j - b_j \sum_{i=1}^{n} q_{ij}$$

A producer i can supply the j markets, under constraint of capacity K_i that is to say that:

$$\sum_{j=1}^{m} q_{ij} \leq K_i$$

3. COMPETITION IMPLEMENTATION METHODOLOGY

The electricity market is a branch of microeconomics, based on the assumption of competition. The modern study of competing firms relies almost exclusively on game theory to analyze the strategic interactions in the actual market.
Competition can be pure and perfect if these four conditions are met:

- Market atomicity;
- Product homogeneity;
- Free entry or exit from the market;
- Complete information.

3.1 Oligopoly modeling

Oligopoly refers to a form of market, where there are often a number of competitors in the market but not enough to consider each of them to have a negligible effect on the price. Oligopoly models differ according to the sector of activity and the number of companies.
Suppose that our electricity market groups n firms, according to Cournot each firm maximizes its profits as follows:

$$\pi_i(q_1, q_2, \dots, q_n) = p(Q)q_i - C_i(q_i)$$

$$= \left[a - b\left(\sum_{j=1}^{n} q_j\right) - c_i\right] q_i$$

According to the dynamic and deterministic model, the total expected profit from period k until the end of planning period $J_k(x_k)$ is expressed by:

$$J_k(x_k) = max\left(\sum_{f=0}^{F-1} \frac{g_{k+f}(x_k)}{(1+r)^f} + \frac{J^*_{k+F}(x_k + u_{k,i})}{(1+r)^F}\right)$$

A Cournot-Nash equilibrium is a vector of non-negative production levels (q_i^*) such that:

$$\max_{q_i \geq 0} \Pi_i(q) = q_i p(q_i + Q_i^*) - C_i(q_i)$$

$$Q_i^* = \sum_{j \neq i} q_j^*$$

This variational inequality can therefore be written:

$$\sum_i [a - 2bq_i^* - C_i(q_i^*)][q_i - q_i^*] \leq 0$$

La solution de cette dernière équation sera :

$$\max_Q \int_0^Q (a - bz)dz + \max_q \sum_i \int_0^{q_i} \left(-bz_i - C_i(z_i)\right) dz_i$$

3.2 Game formulation

Based on oligopoly modeling and taking into account the following assumptions for the electricity market.
1. All the players are fixed and noted
2. The set of strategies If of player i is compact and convex
3. Capacity constraints with constant marginal cost
4. Games in two stages: choice of production scale and price competition
5. Repeated games therefore simultaneous We will model the actions and possible movements of actors in a dynamic framework using a static theory.

The number of players depends on the capacity to ensure, depending on the weather; since consumer demand is never constant. At time *t*, after calculating the distribution of loads in an interconnected network; we define :

(1) The overall state of the power to be supplied ΔP_T^t;

(2) The production of each old operator $P_{inst,i}^t$ with the initial installed capacity $P_{init,i}$;

(3) The maximum capacity authorized for an operator on each site $P_{max,i}$.

For a player, we will put his new capacity to install on the network at instant t; including p_i^t for old actors and p_j^t for new operators. All the possibilities for the old $P_i = \{p_i^t\}$, and the new $P_j = \{p_j^t\}$.

Let $N_j^t : \mathbb{R}$, the function number of new sites as a function of its global state of power to ensure ΔP_T^t and of the initial capacity of the old ones:

$$N_j^t = \frac{\sum p_j^t}{p_j^t}$$

3.3 Algorithmic game resolution

The purpose of this game is to know the number of players at a precise and given instant t. For each player i and j.

- Initialization: *t=0;* ΔP_T^t; $P_{inst,i}^t$; y_i; t_{max}
- Calculation of: $P_{max,i} = (1 + y_i)P_{init,i}$ and $p_i^t = P_{max,i} - P_{inst,i}^t$
- Iteration at time *t*: calculate

$$N_j^t = \frac{\sum p_j^t}{p_j^t}$$

$$N_i^t = \frac{\sum p_i^t}{p_i^t}$$

3.3 Probability of electrical energy production

Let us take the example of this production, from the year 2013 to the year 2018. We can distinguish the monthly points, and the annual growth of production.

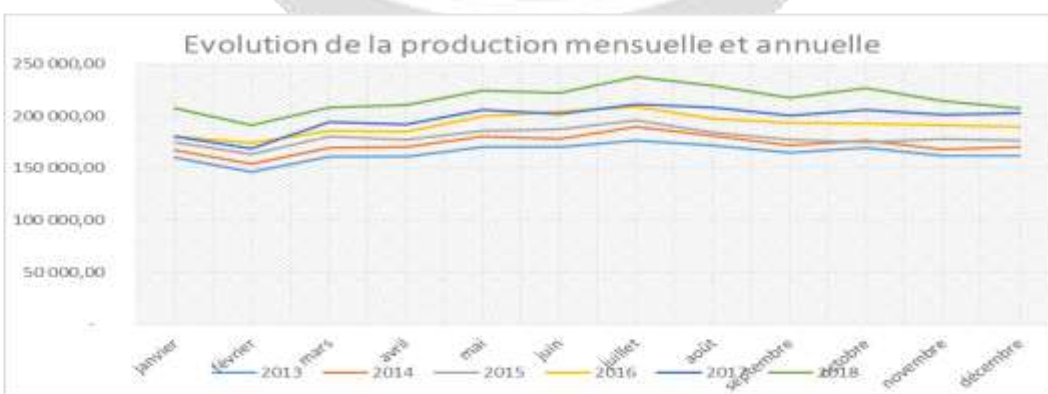

Fig -6: Evolution of monthly and annual production

After calculating the marginal cost, we had the following curve which can define where the investment in this production is the most profitable.

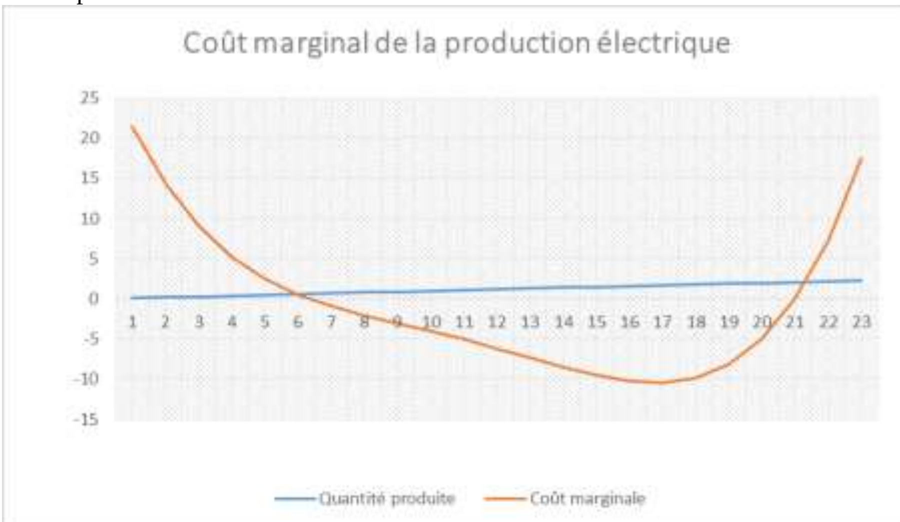

Fig -7: Marginal cost as a function of the quantity produced

By having production planning based on these previous data, we can have a shortfall in relation to the demand of customers and existing firms. By game theory, by considering the electricity market as an oligopoly, we can distribute the powers for each firm in a well-defined electrical energy network.

The electricity network in our example operates with 13% of non-public firms, that is to say the rest of the production is provided by the state. among these private firms, the share of production is not shared equally: with these 13%, the 8% provided by only one company and the 4% by another. For pure and perfect competition, we will distribute this 13% according to the zones and the balance of the interconnected networks as well.

4. CONCLUSIONS

The implementation of competition on the electricity market, according to the 3 common models on competition, was modeled as an oligopoly with n firms. By knowing the distribution of loads in an interconnected network and the production capacity of each existing firm, we can have the balance of the distribution of future productions by game theory. But also, by calculating the marginal cost of the said network, the choice of generation can be made easier by indicating on the marginal cost curve where generation is the most profitable.

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