

OPTIMAL BIDDING STRATEGY FOR GENCOs BASED ON MULTI-OBJECTIVE GENETIC ALGORITHM IN COMPETITIVE ELECTRICITY MARKET

CHIẾN LƯỢC CHÀO GIÁ TỐI ƯU CỦA NHÀ MÁY ĐIỆN DỰA VÀO THUẬT TOÁN DI TRUYỀN ĐA MỤC TIÊU TRONG THỊ TRƯỜNG ĐIỆN CẠNH TRANH

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Abstract - Nowadays, the liberalization in the electricity market is leading to the increase of the completion among participants, including companies (GENCO), Transmission owners (TSOs in Europe and ISOs in the United States of America). Thus, in electricity market, each participant will have responsibility for building their bids to maximize their profits. If one GENCO achieves this, the other can not be satisfied. In general, GENCOs can participate in day-ahead market (pool market), intraday market, and ancillary service. Nowadays, because the closure time is too short, it requires the GENCOs make decision faster and send their bids to Power Exchanges (PXs). It is not only a challenge for player to run some conventional programs but also attracts the researcher. In this paper, the authors present a new methodology to select the best solution in terms of minimal time, and warranty of the global optimal point. The combined methods multi-objectives optimization algorithm (NSGA II) and fuzzy ranking method to select solutions which are compromise among players.

Key words - NSGA-II; bidding strategy; competitive market, Fuzzy ranking method; Pareto front

1. Introduction

In recent years, the liberalization of electricity market develops significantly and become popular in every country since the first idea about electricity market was introduced in America. There are two methods to compute the market price which are Zonal Price and Nodal Price. In fact, the change from Zonal Marginal Price (ZMP) to Locational Marginal Price (LMP) in electricity market structure leads to the adaption of generators, retail companies and Transmission System Operator (TSO) as well. It cannot be denied that the adaption is necessary for each company in highly competitive environment. In the competitive electricity market, dispatch of generation is generated as bids and each generation company GENCO needs to complete with its rivals to maximize their profit.

The bidding strategy was introduced by David in 1993 and has been developed by many researchers, for instance A. Azadeh, Feng Gao, Pathom Attaviriyapap. Generally, there are three main approaches which are Market clearing price forecasting, Rival's bidding modeling, and game based rivals' strategic behavior simulating are used for GENCO strategic bidding [1]. They are classified into the following three categories: optimization models, game theory models and genetic models [2].

Richter, C. W., Jr. and G. B. Sheble [3] proposed an algorithm based on genetic algorithm to generate bidding strategies as GENCOs and DISCOs trade power in 1998. And then, there are many authors who have developed and implemented GA methods for bidding strategy [4-5]. In

Tóm tắt - Ngày nay, sự minh bạch hóa trong thị trường điện đã làm tăng sự cạnh tranh giữa người tham gia thị trường, bao gồm các nhà cung cấp và tiêu thụ. Do đó, mỗi người chơi sẽ chịu trách nhiệm để gửi chào giá với mục đích tối đa hóa lợi nhuận. Tuy nhiên, nếu một người chơi muốn tối đa hóa lợi nhuận thì người khác không thể tối đa lợi nhuận của mình. Nhìn chung, các nhà máy có thể tham gia vào thị trường ngày tới hay thị trường trong ngày và thị trường phụ trợ. Bởi vì thời gian chào giá là rất ngắn nên nó đòi hỏi sự quyết định của người chơi phải nhanh. Vấn đề này không chỉ là thử thách cho người tham gia thị trường mà còn là một vấn đề thú vị cho người nghiên cứu. Trong bài báo này, tác giả phát triển một mô hình để lựa chọn giải pháp chào giá tốt nhất trong khi tối thiểu thời gian tính toán. Mô hình được phát triển dựa trên thuật toán tiến hóa đa mục tiêu và phương pháp lựa chọn ảo.

Từ khóa - NSGA-II; chiến lược chào giá; thị trường điện cạnh tranh; phương pháp Fuzzy; đường cong Pareto

general, these papers propose maximizing the profit of each GENCO. This problem would be not complicated if players (GENCO) public their information before they submit bid to TSO. Unfortunately, it seems to be not easy when players try to keep secret their strategy until the last minute, while the opposite player is trying to forecast rival's bidding strategy by all prices. In this case, it is called it incomplete information game, when players do not know each other's information before they make decision. Our problem is that figuring out the equilibrium point among players, where every player can receive the best trade-off. In paper [6], the problem to be solved implies among adversaries as in game theoretical problems, a variant of the basic GA structure is often adopted as the co-evolutionary genetic algorithm (CoCGA).

In competitive electricity market, the profit of each GENCO is achieved at the maximum, in general, the profit of others cannot be maximum too. Therefore, the optimal solution of all GENCOs is not unique, but in fact, it is a group of solutions which respects a compromise between the profit of GENCOs. Normally, the result is Pareto front and present the set of the feasible solution between GENCOs which can be seen as the compromise solutions. In order to select the best solution which is done by the observation or weighted method. However, if we consider 3 dimensions (it means that we have at least 3 GENCOs), it is too hard to obtain the best solution by the observation. In this paper, the authors propose a new methodology based on two steps: (i) solve bidding strategy by multi-objective optimization (NSGA II), (ii) select the best according to fuzzy ranking method. Here,

the objectives are to maximize the profit of GENCOs in electricity market. Especially, In Intra-day market, with the continuous trading being used and so far, it will become common in Europe regarding to the integration of electricity market in Europe, the market will run immediately when a bid arises. This closure time leads to the big challenge for GENCOs to make decision because they do not have enough time. With fuzzy ranking method, especially Centroid point method, the author can obtain the best solution immediately after the Pareto is obtained.

2. Optimization Problem

2.1. Electricity market

Traditional optimization problem aims to schedule generation resources in order to minimize operation costs while supplying system loads. Generation resources are controlled centrally and information regarding cost, and operation constraints is shared among participants. In this traditional approach, benefit maximization is obtained through cost minimization [7].

The electric power industry is shifting from a scenario in which operation schedule is fully regulated to a new competitive deregulated scenario, in which cost minimization is not equivalent to benefit maximization [8]. In deregulation, electricity price becomes a major issue in the electric industry. Participants of deregulated energy marketplaces are able to improve their benefits substantially by adequately pricing the electricity. The emphasis is given to benefit maximization from the perspective of participants rather than maximization of system-wide benefits [9].

The bids (price signals) are received by a coordinating authority (ISO) who schedules the generation sequentially from the cheapest generating sources until loads are supplied [10]. In general, there are two spot pricing rules including the Uniform Price Auction (UP) and Pay-as-Bid (PaB). The main difference of two auction forms to the producers: under UP all produces which bid below or at the Market Clearing Price (MCP) obtain this price, while under PAB, producers are paid for their bids, as long as this is below or equal to the MCP. According to this, it is observed that decision making in GENCOs' bidding strategy is more important in PAB auction than in UPA [11].

In competitive problem, the objective is to maximize each participant's benefits regardless of its benefits which earn from transactions should be maximized. No doubt, the lower the market price, the higher the net power interchanges. A seller has to evaluate the possibility of either selling more power at a low per unit price or selling less at a high price per unit of power [10]. A similar analysis can be made for a buyer. Each participant anticipates a bid that results in the highest benefits when transactions are defined by the PXs in Europe and ISOs in US. Moreover, each participant defines his bids based on the incomplete information of other participant's bids.

As a transmission congestion configuration is changing for an adjustment in a bid during the iterative process, a

different strategy may become more profitable for some player, and the successive resulting situation can correspond to a different transmission congestion configuration that may give rise to a more profitable strategy for a different player, and so on [4]. The effect of electricity price reacts throughout the market clearing price and taking into account optimization problem. This may be a possible reason for the convergence problems of the parameterization for large systems as pure Nash equilibria may not exist.

Objective:

$$\max \sum_{a \in A} (x_{sd} * Q_{sd} * P_{sd} - x_{ss} * Q_{ss} * P_{sd}) \quad (1)$$

s.t:

$$\sum_{a \in A} (x_{sd} * Q_{sd} - x_{ss} * Q_{ss}) = 0 \quad (2)$$

$$P_{min}^{FA \rightarrow TA} \leq flow^{FA \rightarrow TA} \leq P_{max}^{FA \rightarrow TA} \quad (3)$$

$$0 \leq x_{ss} \leq 1 \quad (4)$$

$$0 \leq x_{sd} \leq 1 \quad (5)$$

$$S_i = MCP_a * x_{ss}^i * Q_{ss}^i, \forall i \in I, a \in A \quad (6)$$

$$S_i = P_{ss}^i * x_{ss}^i * Q_{ss}^i, \forall i \in I, a \in A \quad (7)$$

$$Pr_i = S_i - (a_0^i + a_1^i * P_i + a_2^i * P_i^2) \quad (8)$$

In this paper, the authors use zonal model and ATC method to allocate capacity energy (1) to (5). The revenue of GENCO is taken into account by 2 methods: (i) Uniform Price and (ii) Pay as Bid, equation (6) and (7) respectively. Profit of GENCO is calculated in (8), Revenue minus the cost.

2.2. Linear supply function

In this paper, assume that GENCO in Intra-day market (the payment by Pas as Bid) submits its own bid as pairs of price and quantity in the form of linear supply functions (LSF). And we assume that demand is inelastic.

It means that demand does not change, compared to previously. The LSF takes the following form:

The supply function takes the following form [5]:

$$p_i = \alpha_i * q_i + \beta_i; i = 1, \dots, n \quad \alpha_i > 0 \quad (9)$$

where α_i and β_i are the coefficients of LSF.

LSF with different parametrizations are studied in this paper.

a. a-parametrization, where GenCo i can choose α_i arbitrarily but is required to specify a fixed and pre-chosen value of β_i ($\beta_i = b_i$)

b. b- parametrization, where Genco i can choose β_i arbitrarily but is required to specify a fixed and pre-chosen value of α_i ($\alpha_i = a_i$)

c. ($a \times b$)- parametrization, where GenCo i can choose α_i and β_i subject to the condition that α_i and β_i have a fix linear relationship. The coefficient k_i is used as the bidding variable. The supply function is defined in the following:

$$q_i = \frac{p_i - b_i}{a_i} \quad i = 1, \dots, I; k_i > 0 \quad (10)$$

d. (a,b)- parametrization, where GenCo i can choose α_i and β_i arbitrarily

From [12], Gencos may have incentive to enter market if they decide supply functions using (a,b)- parametrization of LSF in the spot market. The spot market under LSFE type of competition with (a,b)-parametrization or Gencos with tight capacity constraints.

From [13], It shows that when we look for Equilibrium Point, considering Constraint, b parametrization (purple) and (a,b)- parametrization (red) is proposed (Figure 1).

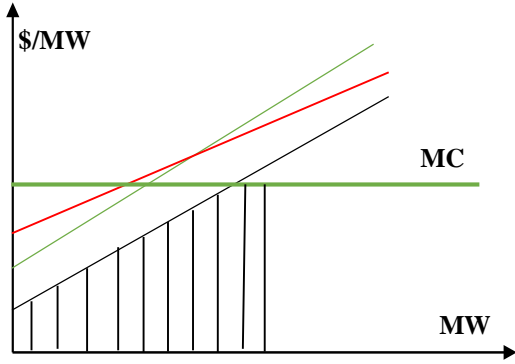


Figure 1. Linear supply function

In this paper, based on [13] and [5], the authors use (a, b) – parametrization to make decision in day-ahead market with the purpose of maximizing profit of generator.

2.3. Objective function

In this paper, optimal bidding strategy is studied from the point of view that GENCO wish to maximize its own profit while considering their rival's bid and their profit functions. Therefore, there is a multi-objective function to be solved. In this case, GENCO maximize its own profit while maximizing rival's profits. Therefore, it is a Co-evolutionary problem in which Profit of generator i (Pr_i) is maximized and described in (10).

$$(Pr_1, Pr_2, Pr_3, \dots, Pr_i, \dots, Pr_n), \forall i \in I \quad (11)$$

with

$$0 \leq a_j^i \leq 2 * a_1^i, \forall i \in I, j \in \mathbb{R} \quad (12)$$

$$0 \leq b_j^i \leq 2 * a_2^i, \forall i \in I, j \in \mathbb{R} \quad (13)$$

Objective function each GENCO is (8), in which profit each GENCO is calculated according to the market price and accepted quantity which are provided by the optimization problem (1). The volume accepted is taken into account from equation 1 to 6, while the Market clearing price is taken into account by the Lagrange multipliers in (2).

3. NSGA II combines Fuzzy ranking method

Over the past decade, multi-objective evolutionary algorithms (MOEAs) have been suggested [1,3]. The main reason is the ability to obtain the multiple Pareto-optimal solutions in one single simulation run. Since evolutionary algorithms (EAs) work with a population of solutions, a simple EA can be extended to maintain a diverse set of solutions. With an emphasis on moving toward the true Pareto-optimal region, an EA can be used to find multiple Pareto-optimal solutions in one single simulation run. The Non-dominated Sorting Genetic Algorithm (NSGA)

proposed was one of the first such Eas. The authors proposed an improved version of NISGA, which they call NSGA-II [14].

Fuzzy ranking method plays a very important role in decision making, optimization and other usages. Numerous ranking approaches have been proposed and investigated in recent years, in which the first method proposed by Jain in 1976 [15]. Then, this method is considered widely and has been applied to many fields. That is the reason why, this centroid point index is used to select the best strategy after we have feasible solutions from Pareto front.

For trapezoidal fuzzy number (a, b, c, d), the centroid whose formulae are described to be are defined in [15]:

$$\bar{x}(\tilde{A}) = \frac{1}{3} * \left[a + b + c + d - \frac{c*d-a*b}{c+d-a+b} \right] \quad (14)$$

$$\bar{y}(\tilde{A}) = \frac{\bar{w}}{3} * \left[1 + \frac{c-b}{(d+c)-(a+b)} \right] \quad (15)$$

Suppose $A_1, A_2, A_3, \dots, A_n$ are fuzzy numbers, the centroid point is taken into account by (14) and (15) of all fuzzy numbers $A_i = (\bar{x}_{A_i}, \bar{y}_{A_i}), i = 1, 2, \dots, n$. After that, we define $G = (x_{min}, y_{min})$. The distance between the centroid point $A_i = (\bar{x}_{A_i}, \bar{y}_{A_i}), i = 1, 2, \dots, n$ and the minimum point $G = (x_{min}, y_{min})$, was proposed as follows:

$$D(A_i, G) = \sqrt{(\bar{x}_{A_i} - x_{min})^2 + \left(\bar{y}_{A_i} - \frac{\bar{w}}{3} y_{min}\right)^2} \quad (16)$$

A bigger value of distance $D(A_i, G)$ indicates a higher ranking of solution.

The most commonly used fuzzy numbers are triangular and trapezoidal fuzzy numbers. In this report, Triangular fuzzy number is introduced and defined as:

$$\mu_{A_2} = \begin{cases} \frac{x-a}{b-a} & a \leq x \leq b \\ 1 & x = b \\ \frac{d-x}{d-c} & c \leq x \leq d \\ 0 & \text{otherwise} \end{cases} \quad (17)$$

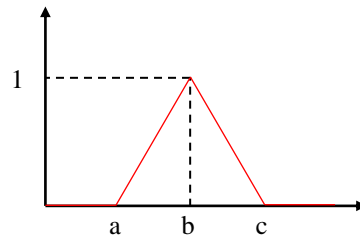


Figure 2. Triangular fuzzy number (a, b, c)

4. Application

4.1. Case study

In this paper, in order to test the proposed method, the author uses a simple network to run market, including two GENCOs and one demand in Figure 3. The demand is inelastic and is supplied by 2 GENCOs, the payment method for 2 GENCOs is Pay as Bid. In Table 2, the parameters of transmission lines and the coefficient of the cost function of each GENCOs are provided.

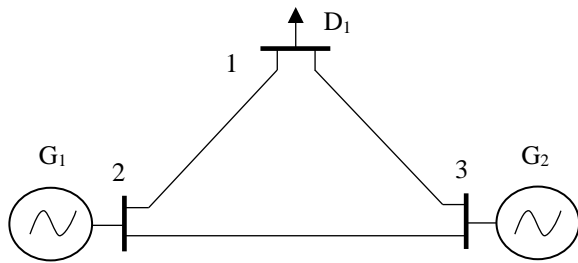


Figure 3. 3-Nodes system

Table 1. Parameter of transmission line

No.	Line	Maximum Capacity(MWh)	Minimum Capacity(MWh)
1	1-2	2500	-2500
2	1-3	2000	-2000
3	2-3	2000	-2000

4.2. Parametrized of algorithm

This study analyzes a simple system to demonstrate the influence of the model in application on bidding strategy. In experiments, settings of the proposed NSGA-II are as follows. The authors build the model in both MATLAB (NSGA II) and GAMS (Optimal Power Flow). On entire optimization problem, the population size and the number of generation are set at 100 and 300, respectively. Crossover probability is fixed at 90%, while mutation probability is inconstant. It is varied at 0.1, 0.16 and 0.2 and four times running for each time. Multi-objective optimization problem performance measures are more complex than single-objective optimization problems. Three issues in a multi-objective optimization [14] are (i) convergence to the Pareto optimal set, (ii) maintenance of diversity in solutions of the Pareto optimal set and (iii) maximal distribution bound of the Pareto optimal set. Too many numerous quality indicators have been suggested by the researchers. The indicator could be classified into three categories depending on whatever they evaluate [15]: (i) closeness to the Pareto front; (ii) the diversity in obtained solutions; or (iii) both (i) and (ii). Finally, fuzzy ranking method is used to rank solutions with Centroid point index. The bigger index the solution has, the more feasible the solution is. It should be noted that the NSGA has been tested with the standard example in [5], and the Optimal Power Flow program provides the same result with Matpower.

Table 2. Parameter of GENCO

GENCO	Capacity (MWh)	a_0 (€/MWh)	a_1 (€/MBtu)	a_2 (€/MWh)
G ₁	2000	600	1.2	0.085
G ₂	3000	335	1	0.123

4.3. Results

Participants try to maximize their profit by submitting bids to power pool. The Optimal Power Flow (OPF) is solved by GAMS and NSGA-II program is built in C++. Pay as Bid is used to pay money for participants instead of

Market Clearing Price the change in payment more clearly. In order to look for the best bidding strategy of participants, they can maximize their own profit; NSGA-II is used to solve this problem. In Figure 3, the typical Pareto optimal fronts are obtained using NSGA-II for this case study. These front show clear relationships among generators. This two dimensional visualization of the tradeoffs may help decision makers choose the most sustainable solution between many feasible solutions. The author would like to notice that our outcome is the maximum of profit each GENCO, but the objective function in NSGA-II is minimizing. Thus, the authors put minus at front of the profit function of each GENCO in order to obtain the maximum profit. In order to help decision maker observe better, the pay-off is weighed with the maximum profit each player. That is the reason why in Figure 4, the x and y axis show us the minimum value is -1, -1 for the maximum profit and 0 for the minimum profit.

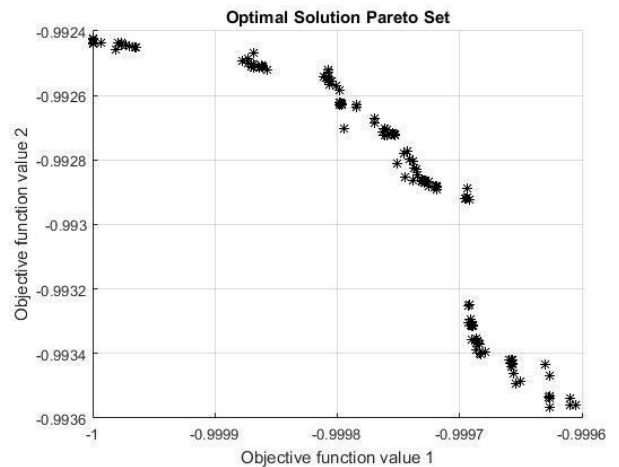


Figure 3. Profit of each generator Pareto front using NSGA-II

After observing results, the case which has 100 populations, 300 generators, and probability of crossover is 90% and probability of mutation is 2% is the most suitable, because it satisfies requirements of three issues in a multi-objective optimization. The evidence are shown in Figure 4 and 5 below. Obviously, in both times, the shapes of Pareto front are similar. Thus, the author can say the program convergence well.

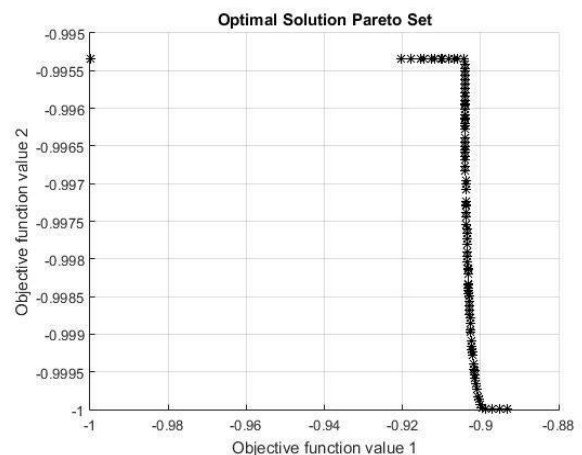


Figure 4. Pareto front using NSGA-II at the first time

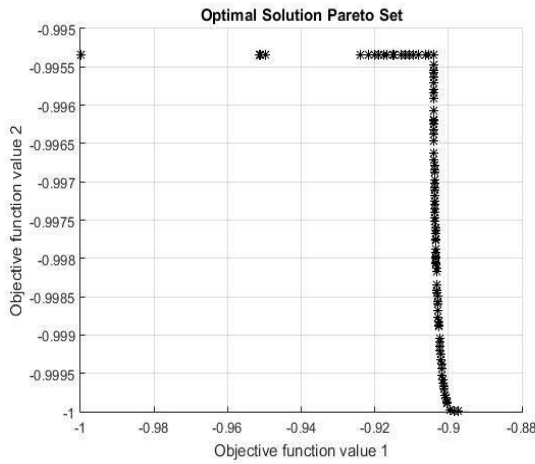


Figure 5. Pareto front using NSGA-II at the second time

Now, we apply the proposed ranking approach to deal with bidding strategy evaluation and selection. Assuming that a solution from feasible solutions (Pareto front) is looking for a maximum profit of producer considering rival's strategy. Two decision makers, i.e. D1 and D2, are responsible for the evaluation of bidding strategies (100 feasible solutions in Pareto front). There are 2 producers so that two criteria may be chosen for evaluating profit of generators: Profit of generator 1 ($C1$), Profit of generator 2 ($C2$). From the evaluation of 2 decision makers, Table 3 shows that there are 2 solutions satisfying decision makers.

Table 3. The most feasible solutions

Solution	a1	b1	a2	b2	Profit1	Profit2
1	1.679	0.163	2	0.246	18325.07	26920.37
2	2.401	0.172	2	0.246	20520.01	26795.03

No doubt that for Generator 2 (Objective function value 2), linear supply function is 2 and 0.246 for $a1$ and $b1$ respectively. If, I were Generator1 (Objective function value 1), the best solution would be 2th. The reason is that player 1 can maximize their profit if they choose strategy 2. Therefore, the best solution in this case is solution 2 in which profit of player 1 and player is 20520.01 and 26795.03 respectively.

5. Conclusion

In this paper, the problem of Gencos' strategic bidding for electricity market is considered. A genetic algorithm (NSGA II) and fuzzy ranking method are chosen as the solution method. Multi-objective optimization problem model can be looked at as a special form of agent-based computational economics model. Each participant in the market is represented by a species in model, and the interactions among market participants are embodied in the co-evolutionary process of the species. The main reason is that NSGA-II was able to maintain a better spread of solutions and converge better in the obtained non-dominated front compared to other elitist MOEAs. After obtaining the list of the feasible solution, Fuzzy ranking method has been adopted to find the best solution in terms of minimal computation time.

Tests are carried out with reference to Pay as Bid

method, using 3-node system. Results show that, with probability of crossover and mutation of 90% and 2% respectively, the problem is coverage. After that, depending on the decision of maker, feasible solutions which can happen, are obtained by fuzzy ranking method. And it is the best solution among the feasible solutions.

LIST OF SYMBOLS

$a \in A$ Set of bidding areas

$i \in I$ Set of generator

$l \in L$ Set of transmission lines

P_{ss}^i, Q_{ss}^i Price and quantity energy of step hourly order supply of generator i , in €/MWh and MWh, respectively.

P_{sd}^i, Q_{sd}^i Price and quantity energy of step hourly order demand of generator i , in €/MWh and MWh, respectively.

$P_{max}^{FA \rightarrow TA}$ Maximum capacity on transmission line l in MWh.

$P_{min}^{FA \rightarrow TA}$ Minimum capacity on transmission line l in MWh.

a_0^i, a_1^i, a_2^i coefficients in cost function of generator i .

x_{ss}^i Clearing acceptance ratio of supply step order of generator i in p.u. $0 \leq x_{ss} \leq 1$

x_{sd}^i Clearing acceptance ratio of supply step order of generator i in p.u. $0 \leq x_{sd} \leq 1$

$flow^{FA \rightarrow TA}$ Power flow on transmission l

MCP_a Market clearing price in bidding area a .

S_i Revenues of Generator i .

Pr_i Profit of Generator

a_j^i, b_j^i Coefficient of linear supply function.

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(The Board of Editors received the paper on 14/3/2017, its review was completed on 28/3/2017)