A New Pool Market Method for Generation Expansion Planning in Restructured Power System

Morteza Thaerkhani [1], Mohammad Sadegh Javadi [2], Amin Javadinasab [2]

[1.] Islamic Azad University, Karaj Branch, Karaj, 2139643711, Iran
[2.] Islamic Azad University, Shoushtar Branch, Shoushtar, 6138663849, Iran
msjavadi@gmail.com

Abstract: The issue of generation expansion planning (GEP) is more complicated in the restructured and modern power systems rather than traditional and monopoly systems. In Modern power systems, each Generation Company (Genco) invests in the section of generation in order to get to his own maximum profit. This paper presents a new mixed method to solve the GEP problem in Power Pool Market. This method is formed of two levels: local level and national level. In local level, each of Gencos declares his own generation level to Independent System Operator (ISO) aiming maximize the profit just with respect to local constraints. In national level, first the competition between Gencos will be modeled by game theory and Nash-Cournot equilibrium. Then, due to the generation level of each of Gencos, the system national constraints will be checked. If these constraints would be satisfied, problem-solving would be completed but if each of these constraints won't be satisfied, their relevant coefficients will be changed in problem and this procedure would be repeated again and again until problem was converged to accepted solutions which satisfy local and national constraints.
[Morteza Taherkhani, Mohammad Sadegh Javadi, Amin Javadinasab, A New Pool Market Method for Generation Expansion Planning in Restructured Power System. Journal of American Science 2011; 7(2):620-624]. (ISSN: 1545-1003). http://www.americanscience.org.

Keywords: Generation Expansion Planning, Pool Market, Game Theory, Uncertainty

Nomenclature

T: Time horizon of planning
m: Number of generation technologies
p(t): Price of power sale in year t_{th}
q(j,t): Quantity of that power which is generated by technology *j* in year t_{th}
B_i: Sum of profit of i_{th} Genco in generation planning
C(j,t): Cost of power which is generated by technology *j* in year t_{th}
EM(j): Emission coefficient of technology *j* and
EML(t): Allowable emission margin in year t_{th}
MaxExp(t): Maximum level of expansion in year t_{th}
$C_{inv}(t)$: Cost of investment per year
MaxCap(t): Maximum rate of investment of each investor in year t_{th}
$r_{\min}^{t}$: Down reserve margin
$r_{\max}^{t}$: Up reserve margin
h: Allowable level of LOLE

1. Introduction

In Generation Expansion Planning (GEP), the generation level of each of generation company (Genco) in market would be specified in a determined time horizon. The Gencos will also regulate their own investment plans with respect to this planning. The establishment of restructuring in Power Industry has greatly influenced GEP. In a traditional system, the main objective is to minimize the total of generation costs, but in a modern power system (restructured environment), Gencos as players in power market just want to maximize their own profit and they accomplish their generation planning in order to achieve this aim (Kagiannas et al., 2001). In such an environment, ISO has a duty to control market in generation, transmission and distribution sections. In generation section, ISO applies the system constraints in GEP problem (Murphy and, Smeers, 2001).

In this paper, in the first stage, ISO takes into consideration the local constraints of system like emission constraint, fuel constraint and etc for each Genco. Having applied these constraints, each Genco will specify his own generation level in a planning horizon. In the second stage, after competing Gencos in a game and achieving Nash-Cournot equilibrium, ISO checks the national constraints of system like LOLE and reserve constraint with respect to the sum of Genco's generation in pool market (Torre, et al., 2003). Finally, the problem would be converged to some solutions which satisfy local and national constraints.

2. Material and Methods

In a traditional power system, the aim is to minimize the sum of system costs but in a modern power system, the objective function is in the form of total of profit gained by generation for each of Gencos and this profit must be maximized (Lin et. al., 2004). The problem's constrains are different as compared with traditional case, because some constraints like financial limitation of investment and the maximum constraint of generation level will also be applied in problem per year for every Genco, in order to prevent creating the market power, in addition to traditional environment's constraints like emission constraint, fuel constraint and etc.

1- Objective function

For *ith* Genco, the objective function will be written as follows:

$$Max \;\; B_i = \sum_{t=1}^{T}\sum_{j=1}^{m}[\,p(t).q(j,t) - C(j,t)] \qquad (1)$$

Here, *T* is the time horizon of planning, *m* is the number of generation technologies (thermal, Gaseous, nuclear, etc.), *p(t)* is the price of power sale in year *t-th*, *q(j,t)* is the quantity of that power which is generated by technology *j* in year *t-th* and *Bi* is the sum of profit of *i-th* Genco in generation planning. *C(j,t)* is the cost of power which is generated by technology *j* in year *t-th* and is expressed by equation (2).

$$C(j,t) = \frac{1}{2}a.q^2(j,t) + b.q(j,t) + c \qquad (2)$$

Here, *a*, *b* and *c* are cost function coefficients.

2- Local constraints

I) Emission constraint: this constraint controls the emission level of various technologies of generation.

$$\sum_{j=1}^{T} q(j,t).EM(j) \le EML(t) \qquad (3)$$

Here, *EM(j)* is the emission coefficient of technology *j* and *EML(t)* is the allowable emission margin in year *t-th*.

II) The constraint of maximum expansion level will be specified for each Genco per year by ISO and it causes to prevent creating market power and competition-escaping.

$$\sum_{j=1}^{m} q_i(j,t) \le MaxExp(t) \qquad (4)$$

In this equation, *MaxExp(t)* states the maximum level of expansion in year *t-th*.

III) The financial constraint of investment is related to each investor.

$$C_{inv}(t).\sum_{j=1}^{m} q_i(j,t) \le MaxCap(t) \qquad (5)$$

In this equation, $C_{inv}(t)$ $C_{inv}(t)$ is the cost of investment per year and *MaxCap(t)* states the maximum rate of investment of each investor in year *t-th*.

3- National constraints

I) Reserve constraint: the sum of generation per year must between up and down reserve margin.

$$(1 + r_{\min}^{t})D(t) \le \sum_{i=1}^{n} q_i\,(t) \le (1 + r_{\max}^{t})D(t) \qquad (6)$$

Here, $r_{\min}^{t}$ is the down reserve margin and $r_{\max}^{t}$ is the up reserve margin.

II) *LOLE* Constraint: In year *t-th*, *LOLE* rate must be lower than its allowable level.

LOLE (t) ≤ h (day/year) (7)

Here, *h* is the allowable level of *LOLE*.

In a GEP problem with n candidate for expanding generation, generating quantities for each Genco (*qi*) should be specified in planning horizon (*T* years):

$$q = \overbrace{\begin{bmatrix} q_{11} & q_{12} & . & . & . & q_{1T} \\ q_{21} & q_{22} & . & . & . & q_{2T} \\ . & & & & & . \\ . & & & & & . \\ . & & & & & . \\ q_{n1} & q_{n2} & . & . & . & q_{nT} \end{bmatrix}}^{T\ years} \Bigg\} n\ Genco$$

Game theory is used in order to solve the problem of GEP in national level and modeling the competition among Gencos. In this algorithm, the necessary data like Market Clearing Price (MCP), fuel limitation, Reserve Margin and the index of reliability will be declared by ISO to every Genco. In local level, Each Genco accomplishes its own generation planning aiming maximize its profit. The planning results of every Genco will be declared to ISO which is including the total of new added capacity by various generation technologies. ISO declares those results which are relevant to planning of every Genco to all other Gencos.

In next stage, in local level, each of Gencos will solve the GEP problem more accurately with respect to the latest results of other Genco and they make their results update and then send results to ISO. This procedure is like a game to Nash-Cournot equilibrium (Chaung, et. al., 2001). This game goes on until none of Gencos Wouldn't like to change their own generation level in planning horizon. Since decision-making of Gencos happens simultaneously and competition between Gencos is based on quantity, these conditions state that they have achieved the Nash-Cournot equilibrium (Cournot, 1897). Then, in national level ISO will check the system national constraints (Equations 6 & 7) with respect to output results of Gencos. If these results would satisfy the national constraints of system, ISO confirms the results corresponding to planning and the problem-solving will be completed, otherwise when each of national constraints wouldn't be satisfied as well as disapproval of planning results, the problem should be resolved applying some changes.

These changes will be applied in problem using some coefficients α and β which are related to reserve constraints and *LOLE*, respectively.

Having used these coefficients, Equations (6 & 7) will be corrected as Equations (8 & 9):

$$(1+r_{\min}^{t})D(t) \le (1 \pm \alpha)\sum_{i=1}^{n} q_i\,(t) \le (1+r_{mac}^{t})D(t) \quad (8)$$

$$(1-\beta)LOLE(t) \le h\ (day/year) \quad (9)$$

If the sum of existing and added generation would be higher than up reserve margin, α coefficient should be gradually decreased in equation (8) and if the sum of existing and added generation is lower than down reserve margin, α coefficient should be gradually increased in equation (8). In equation (9), in order to achieve the considered level of reliability in national level changes in β coefficients is used, Gencos have to gradually decrease the considered LOLE indices (Kirschen, and Strbac, 2004).

The problem will be resolved for every Genco by applying these changes (Javadi, et. al., 2009). If each of national constraints would be disregarded, Each Genco applies equations (8 & 9) with new and changed coefficients in their planning problem. For example, if equation (8) wouldn't be satisfied and the sum of generation is lower than down reserve margin, ISO forces each of Gencos to increase their generation in order to achieve the considerable degree while it increased α coefficient because in normal condition, none of Gencos have no inclination to change their generation level in planning horizon while they are achieved their premium planning and maximum profit.

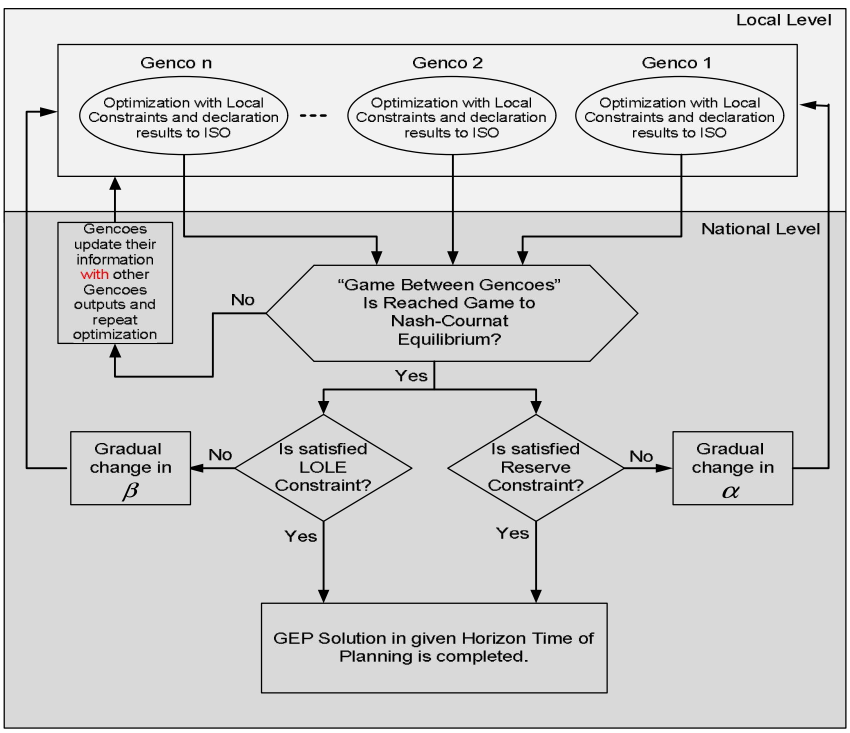

Figure1. Pool Market method flowchart for GEP

This procedure goes on until all national constraints would be satisfied. In this stage, planning has Nash-Cournot equilibrium and none of constraints check would be disregarded. Therefore, these results will be taken into consideration as final results of GEP. The flowchart of GEP in a Power Pool Market is given in Figure.1.

3. Results

In this paper, 3 Gencos who had various generation technologies will compete together in order to expansion the generation in a pool market. The data related to these technologies are given in Table 1 (Su et. al., 2000).

Table 1. The data related to generation technologies

Generation Technology	No. of Units	Capacity (MW)	Max. Expansion in Year (no. of units)
Nuclear	2	650	1
Coal 1	2	400	2
Coal 2	2	200	3
Oil	2	300	3
Comb. Tur.1	2	50	5
Comb. Tur.2	4	25	5

These 3 Gencos have 6 choices for type of technology of generation unit altogether which includes nuclear, coal (2 types), oil and combustion. Turbine (2 types).The number of generation units, maximum of expansion level for every unit per year and generating capacity of these units are determined in this table. Some technical and economical data of these generating units such as maintenance, fuel and investment cost and Forced Outage Rates (FOR) are given in Table 2. The horizon of planning is considered for 5 years.

Table 2. Technical and economical data of candidate units

Unit Type	Maintenance Cost ($/MW)	Fuel Cost ($/KWh)	Capital Cost ($/KW)	FOR
nuclear	113.75	2.41	625.5	0.05
Coal 1	516	4.21	635	0.09
Coal 2	450	4.21	595	0.15
Oil	195	11.3	255.75	0.36
Comb.Tur.1	235	12.16	152	0.015
Comb. Tur.2	145	12.5	100	0.007

It is supposed that information related to 10 years from 1999 to 2008 such as load peak and the average of electricity sales price are available and the planning of generation expansion has to be executed in this time horizon while we used the forecasted information related to 5 next years from 2009 to 2013.

Table 3. Load peak and average of electricity sales price in past 10 years

Year	Load(MW)	Average Price($/MW)
1999	17465	9
2000	18821	10
2001	19805	11
2002	21347	12
2003	23026	14
2004	24750	15
2005	27107	15.5
2006	29267	16
2007	32200	18
2008	34200	19

The amount of load peak and its price in past 10 years is according to Table 3. With respect to information of Table 3 using (Auto Regressive Integrated Moving Average (ARIMA) method (Abraham and Ledolter, 1986), the level of load peak and the average of electricity sales price will be forecasted in next 5 years. The forecasted values are given in Table 4.

Table 4. Forecasted values of load peak and average of electricity sales price

Year	Load (MW)	Average Price ($/MW)
2009	36652	19.5
2010	38765	20
2011	41120	21
2012	43242	22
2013	45462	22.5

Three modes are taken into consideration for load:

- Peak load mode: load is equal to values of table 4.
- Average load mode: load is equal to %90 values of load peak values.
- Base load mode: load is equal to %80 values of load peak.

The capacity which is installed in 2008 is equal to 35000 MW. The rate of LOLE is 5 (days/year) and reserve margin is between 5% -15 %. The value of initial coefficients is related to reserve constraint (α) and confidence capability (β) is 25 MW and 0.001.

Due to the flowchart of this model in Figure 1, Gencos will compete together in order to maximize their profit firstly. As it is mentioned before, this competition is modeled by game theory and since decision-making of Gencos would be simultaneously happened, the Nash-Cournot balance point will be created in this game. The change of total generation for each Genco and achieving Nash-Cournot equilibrium in first year of planning is shown in Figure 2.

Load has no definitive mode and it is mixed of three peaks, average and base modes and a coefficient-giving to three modes of load will be performed in order to achieve the load rate in these conditions with respect to seasons of year. As we know electricity consumption is in peak mode in summer usually and it is in average mode in fall and spring seasons and it is in base mode in winter, i.e.: the lowest value.

Therefore, we can consider the consumption load in a year with an appropriate approximation like the following:

The year consumption load = peak load of year $\times$ 0.25 + average load of year $\times$0.5 + base load $\times$0.25

By using represented method in this paper, the results related to generation expansion plans in a planning horizon are in the form of Table 5 and Figure 3.

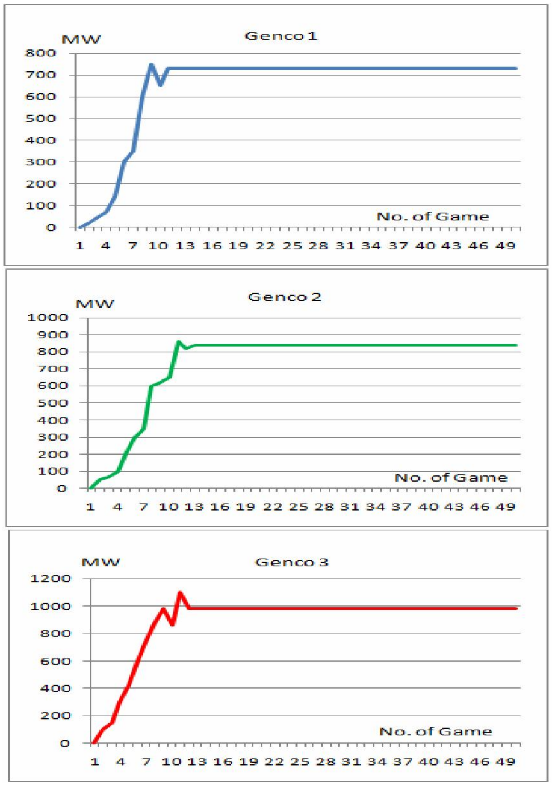

Figure 2. The change of total generation for each Genco and achieving Nash-Cournot equilibrium in first year of planning

4. Discussions

In represented model in this paper for solution GEP problem in pool market, new electricity market concepts such as forecasting, game theory and etc are combined with GEP problem in modern system. This combination bring about the comprehensive and accurate model for solution GEP problem. In our study, this concept is never used synthetically. Besides using these concepts in the represented model, a simple method is used for convergence the problem answer to the answer that maximizes the Gencos benefit. In this model, ISO leads the solution problem to a direction that the Genco should oblige to exist from its production optimized manner a little to satisfy the overall constraints which are as the security constraints of network by exertion some coefficients in the constraints and finally the overall constraints are satisfied. In this model GEP problem is simulated in addition to applying new concepts of electricity market with a simple but useful method and present an optimal and reasonable answer for the GEP problem.

Corresponding Author:
Mr. Mohammad Sadegh Javadi
Islamic Azad University- Shoushtar Branch, Shoushtar, 6138663849, Iran
E-mail: msjavadi@gmail.com

References

1. A. G. Kagiannas, D. T. Askounis, J. Psarras, “Power generation planning: a survey from monopoly to competition”, Electrical Power and Energy Systems 2004, 26(6):413-21.
2. Murphy FH, Smeers Y. “Capacity expansion in imperfectly competitive restructured electricity markets”. Harvard Electricity Policy Group, Center for Business and Government; 2001, 13(3): 354-60.
3. S. de la Torre, A. J. Conejo, and J. Contreras, “Simulating oligopolistic pool-based electricity markets: A multi-period approach,” IEEE Trans. Power System; 2003,18(6):1547–55.
4. Lin WM, Zhan TS, Tsay MT, Hung WC. “The generation expansion planning of the utility in a deregulated environment”; IEEE conference on electric utility deregulation, restructuring and power technologies 2004, 17(2): 702–7.
5. A. S. Chaung, F. Wu, and P. Varaiya, "A game-theoretic model for generation expansion planning: Problem formulation and numerical comparisons," IEEE Trans. Power Systems, 2001, 16(5):885-91.
6. Cournot A. Researches in to the mathematical principles of the theory of wealth. New York: Macmillan; 1897.
7. D. Kirschen, G. Strbac, Fundamentals of Power System Economics. John Wiley & Sons. 2004.
8. M. Javadi, R. Azami, H. Monsef, Security Constrained Unit Commitment of Interconnected Power Systems, International Review of Electrical Engineering I.R.E.E, 2009, 4(2), 199-205.
9. Su CT, Lii GR, Chen JJ. “Long-term generation expansion planning employing dynamic programming and fuzzy techniques” IEEE proceedings of Conference on industrial technology, 2000, 2:644–9.
10. Abraham, B. and Ledolter, J. Forecast functions implied by autoregressive integrated moving average models and other I-elated forecast procedures. Strrtist. Refi. 1986, 54:51-66.

2/9/2011