The Power Reserves Market Creation For The Participants Maximum Benefit

Anatolij Mahnitko, Tatjana Lomane, Sergej Ribakov
Riga Technical University, the Institute of Power Engineering,,
1 Kronvalda Blvd., Riga LV-1010, Latvia,,
E-mail: mahno@eef.rtu.lv, loman@eef.rtu.lv , s.ribakov@inbox.lv

Abstract **–** It is known, that the main task of the electric power system (EPS) control is the power supply providing with the minimum expenses for the electric power production. In this case the requirement to the electric power quality, power supply reliability and the limitations on the energy resources cost must be observed. The power reserve presence into EPS is the necessary condition of the guaranteeing the normal operation from the point of view of the regime parameters values. In the proposed paper the problem of the developing the power reserve, presented to sale by the electric power producers, is examined. It is considered the procedure of the power reserve price determination.

Keywords: ***electric power, power market, reserve, optimization, price***

I. INTRODUCTION

The market relations and the competition between the electric power users and producers considerably increased the number of problems, which characterize the electric power systems (EPS) operation. The structure of these relations led to the creating the new class of the tasks, which did not occur before the introduction of the market mechanisms into the power engineering control. It is appeared such tasks as: the analysis of the electric power supply and demand, the power commercial reserves determination and optimization for EPS, the formation of tariffs, the simulation of the technical services market, etc [1-10]. It is arisen, in particular, the need of the consideration of the EPS separation into the financial independent subsystems with the saving of the power and electrical unity for the operational regimes of these subsystems. For example, it is characteristic for Baltic countries EPS, etc.

The financial interests of the individual energy companies often contradict with the criterion of the united electric power systems effective operation. For this reason it is necessary the corresponding mathematical apparatus, which considers the possibility of the contradictory or different criteria co-ordination for the individual systems [2]. Under the market conditions the consideration of these contradictions is achieved by the providing the power supply and demand balance in the cost expression. The experience of the world practice shows [7, 9], that the principles of the energy wholesale markets organization for the different countries and energy companies can essentially be differed. The basic difference in this case is the electric power prices (tariffs) formation in depending on the level of the wholesale market. Here it can occur the internal tariffs of the energy company and the tariffs of the regional wholesale market for the energy companies associations, which can be different.

Thus, the objects, which determine the electric power prices for the power flows along the intersystems connections, are the participants in the wholesale market and the independent territorial energy companies. The following is one of the strategies for the wholesale price formation:

- the energy companies with the power excess will give the claims for the electric power sale through the wholesale market (price, capacitate);
- the energy companies with the power deficit will give the claims for the electric power purchase through the wholesale market (capacitate);
- the selection of the wholesale price begins with the minimum price, which is proposed in the claims.

Then, in the order to increase all prices and corresponding to them the proposed electric power capacitate, which participates in the covering of the declared load, are examined. The selection is finished on the price of that energy company, which provides the system load covering. Thus, in the current moment the remaining energy companies are not included in the wholesale market operation and thus they incur losses by reason that they too increase the price and cannot realize their power surpluses. Consequently, the wholesale price is defined as maximum price, that participates in the load covering.

For the making the effective solutions for EPS development and exploitation the deeper technical and economic analysis of the different operation conditions is required. The optimization of these regimes must be calculated taking into account the criteria of quality, efficiency, reliability, permissibility and technical realizability. In this case on principle is the obliged concideration of the existing requirements for the power plants operation by the minimum influence on the environment.

It is possible to confidently assert, that within the framework of the whatever economic system the power system functioned, the problems of the regimes optimization have the priority meaning. Under the market economy conditions the urgency of this task immeasurably grew. Its solution gives the possibility to the thermal and electrical energy producer to increase the competitive ability on the electric power markets. With the larger authenticity it is calculated the volumes and the structure of the burnt fuel for the prospect, it is found the weak places in the technological process.

II. EPS REGIMES OPTIMIZATION IN THE COMPETITORY MARKET

With the cancellation of the electric power regimes centralized regulation the problem of the development for the optimal power flow determination procedures, which consider the additional market - oriented limitations, becomes urgent. With the regime control realization in the competitory environment the system operator (SO) is forced each its solution to base by the calculations, which confirm its effectiveness and efficiency. The change of the control principles requires the revision of the approaches to the classical formulation of the regimes optimization problem, which successfully functioned in the vertically – integrated energy companies.

It is known, that in the classical formulation of the regimes optimization problem, as the criterion of the system operational dispatcher was taken the load active power optimal distribution between the generating sources to provide the minimum of the standard fuel expenses [10].

This was reached at the equality condition of the relative increases for the fuel-cost function:

$$\varepsilon_1 = \varepsilon_2 = ... = \varepsilon_n = \varepsilon_b , \qquad (1)$$

where $\varepsilon_i = \dfrac{\partial C_i}{\partial P_{gi}}$ is the characteristics of the relative increases for the fuel-cost function C_i in the i node; $i = \overline{1,n}$ is the node number; n is the generating sources amount, including the balancing node b (ε_b).

In the traditional regulated market the mathematical problem of the regime optimization was formulated as the minimization of the summary expenses for the electrical energy production:

$$\min_{P_G} \sum_{i=1}^{G} C_{gi}(P_{gi}) , \qquad (2)$$

where $C_{gi}(P_{gi})$ are the summary expenses of P_{gi} power production for each individual participant in the market.

For the users the criterion of the regime optimality is determined by the smallest cost of the claimed generation:

$$\frac{\partial C_{g1}}{\partial P_{g1}} = \frac{\partial C_{g2}}{\partial P_{g2}} = ... = \frac{\partial C_{gG}}{\partial P_{gG}} , \qquad (3)$$

with the condition of the covering the load full power and the corresponding the equality of the short term maximum expenses for all generators.

In the object model of the competitory electric power wholesale market (EPWM) it is accepted the condition of the welfare function (WF) maximum for the market participant as the optimization criterion [6, 10-12]:

$$\left(\sum_{\ell \in L} c_\ell \cdot P_\ell - \sum_{g \in G} c_g \cdot P_g \right) \to \max \qquad (4)$$

with the limitations to the power flows P_{ij} from the node i into the node j along the line i-j or for the power flows sum through the controlled sections (groups of lines) S :

$$P_{s\,min} \le \sum_{(i,j)\in s} P_{ij} \le P_{s\,max} , \; s \in S , \qquad (5)$$

and also the balance limitations with according to the active and reactive power in the nodes:

$$\left. \begin{aligned} \sum_j P_{ij}(U_i, U_j, \delta_i, \delta_j) + \sum_{g\in G_i} P_g - \sum_{\ell \in L_i} P_\ell = 0, \; i \in N, \\ \sum_j Q_{ij}(U_i, U_j, \delta_i, \delta_j) + \sum_{g\in G_i} Q_g - \sum_{\ell \in L_i} Q_\ell = 0, \; i \in N, \end{aligned} \right\} \qquad (6)$$

and the limitations to the range of the change for the optimizable variables:

$$\left. \begin{aligned} P_{g\,min} \le P_g \le P_{g\,max}, \; g \in G, \\ P_{l\,min} \le P_g \le P_{\ell\,max}, \; \ell \in L, \\ Q_{g\,min} \le Q_g \le Q_{g\,max}, \; g \in G, \\ U_{j\,min} \le U_j \le U_{j\,max}, \; j \in N \end{aligned} \right\} , \qquad (7)$$

Where c_g, c_ℓ are the claims prices for the active power production (sale) and consumption (purchase);

P_g, P_ℓ are the nodes capacities of the active power production (sale) and consumption (purchase);

P_{ij}, Q_{ij} are the active and reactive power flows along the line i-j from the node i into the node j ;

Q_g, Q_ℓ are the nodes capacities of the reactive power production and consumption;

U_j, δ_j is the voltage module and phase of the node j;

G, L is a great number of the nodes claims for the active power production (sale) and consumption (purchase);

G_i , L_i is a great number of the nodes claims for the active power production (sale) and consumption (purchase) in the node i;
N is a great number of the electrical network nodes;
S is a great number of the controlled sections.

The mathematical formulations of the tasks (1) and (4) are similar, but it is had the significant differences, determined by the specific character of the forming the power flows market-optimum distribution. The basic differences is the following [10]:

- the need of the using the solution methods, which can combine the reliability, the stability and the rapidity during the obtaining the results, and also which are capable to consider the limitations on the equalities and inequalities types;
- the changing the number of the additional functional limitations for the inequalities type, for example: the power limitations at the controlled sections, the generators limitations on the minimum (maximum) power generation, the generators rates limitations during the stop and start process, etc.;
-in the depending on the problem formulation the optimization objective function can includes the different by their nature characteristics. This can be, for example: the relative increases for the fuel-cost function (FCF), based on the fuel expenses physical characteristics of the equipment; the tariff-price functions (TPF), asserted by the energetic commissions; the price claims (PC) of the generators and the wholesale buyers, sent to the competitory electric power market;
- the algorithms of the limitations registration must be speed, without the requiring the complete calculation of the operation regime.

Function (4) shows, that the WF maximum achievement in the considerable extent depends on the electric power market price. It is known [4, 6, 10], that during the electric power price formation the equality of the price and the cost relative increases of the electric power production (taking into account the network losses) is the optimum market strategy. This price is determined on the increases basis (the marginal approach is the production cost changing during the small (single) increases of the evaluated power) and it is frequently called the marginal price. It goes without saying, the market price will differ from the marginal price, since it additionally includes the benefit component , it depends on supply and demand and it is limited in according with the social and political factors.

3. CREATION OF THE POWER RESERVES

For the electric power supply reliability and high quality electric power providing, the independent EPS, which work in parallel, are forced to agree on their regimes [2-4, 13-15]. The attraction of one EPS administrations and resources for the aid to another EPS it is considered as the technical services, which have the specific limitations and cost. The creation of the power reserve in the adjacent EPS is one of such paid services. The specific character of this service lies in the fact that it is tightly connected both with the current regime and with the future possible situations. These situations can be caused as by the failure of the power stations equipment of the considered EPS or by the load increase of its users, etc. Under conditions of the territorial and economic disintegration the realization of the market relations strategy, in particular "the contractual deliveries", where is provided the significant penalty for the power undersupply and "the local selfishness", it is possible only, when the necessary reserve of the generating power, etc. is present [2, 10, 13, 14, 15]. Otherwise the adjacent energy company will not be able to render the necessary aid for another [2-4, 10, 13-16]. Consequently, the guarantee of the reserve is the service, in which both the individual market participants and entire EPS as a whole are interested. The creation of the necessary capacity for the revolving power reserve is the component part of the market "on day forward".

The urgency of the power reserves market creation is the additional evidence of the revision and correction need for the problems formulations of EPS regime calculation, the utilized mathematical models and the methods of their solution. It is known the different formulations of the tasks, connected with the the power reserves consideration [14-18]. It is seemed that more advanced is the model of the task, given in [15].

For the participation in the power reserves market the electric power producer in the node (i) has possibility to distribute his production power by two parts. One of them (P_{gi}) he can declare in the form of generation and sell on the price c_{gi} , and the power capacitate second part he can leave as the underloaded generators (R_i) and sell on the price c_{Ri}. The power reserve in the node i can be determined from the expression:

$$P_{gi} + R_i = P_{gi\,max} \tag{8}$$

If the reserve R_i does not realize, then the time unit benefit B_i of the node producer can be defined as

$$B_i = c_{gi} \cdot P_{gi} + c_{Ri} \cdot R_i - C_{gi}(P_{gi}) \ , \tag{9}$$

without the consideration of the costs for the aggregates start and stop.

In the equation (9) the value $C_{gi}(P_{gi})$ are the power production costs for the time unit in the node i. These costs are determined by the fuel-costs function

$$C_{gi}(P_{gi}) = \alpha_i + \beta_i \cdot P_{gi} + \gamma_i \cdot P_{gi}^2 \tag{10}$$

The node power generation must satisfy to the technological limitation (7).

For the i node producer the electric power optimum price with the point of view its maximum benefit, can be defined as the result of the problem solution for the function (9) unconstrained optimization by the variable P_{gi}. From the condition of the equality to zero the first derivative of the function (9) by the variable P_{gi} with taking into account the function (8) it is shown the following equation:

$$\frac{\partial B_i}{\partial P_{gi}} = c_{gi} - c_{Ri} - \frac{\partial C_{gi}(P_{gi})}{\partial P_{gi}} = 0 \quad (11)$$

The power value P_{gi}, which the node producer can propose for the power market, can be determined by the using the function (11). This power is represented in the form of the dependence on the power prices on generation (c_{gi}) and reserve (c_{Ri}). For the consider task we obtain dependence as follow:

$$P_{gi}(c_{gi}, c_{Ri}) = \frac{c_{gi} - c_{Ri} - \beta_i}{2\gamma_i} \quad . \quad (12)$$

The checking the extremum nature of the benefit function (9) with the aid of the second derivative sign leads to the following result:

$$\frac{\partial^2 B_i}{\partial P_{gi}^2} = -2\gamma_i \prec 0 \quad . \quad (13)$$

The negative value of the result function shows the reaching the maximum value for the function (9) with the generating power value P_{gi}, which is equal to the proposed market power.

In the case of the determining the commercial benefit for the system as a whole the electric power optimum price for the node producer can be determined with the use of Lagrange function as follow:

$$L = \sum_i B_i + \sum_i \lambda_i \cdot (P_{gi} + R_i - P_{gi\,max}) \quad . \quad (14)$$

With the economic point of view the variables λ_i (Lagrange's coefficients) are interpreted as the shady prices of the resources, determined by the limitations function (8). It is made equal to zero the partial derivatives by the variables P_{gi}, R_i, λ_i and the necessary conditions of the function (14) extremum are determined [1, 12, 19]. The solution of the obtained equations gives the extremum point , which must be investigated to the maximum (or the minimum). The determination of the extremum form (maximum or minimum) can be fullfiled with the aid of Sylvester criterion [19], which is well-known in mathematics. According to this criterion the investigated extremum point will be the minimum, if the determinants of all degrees of Hesse matrix for the function (14) are positive.

With the being steady of the equilibrium price (EP) $c_* = c_{gi}$ at the power market it can be determined the optimum price c_{Ri} of the power reserve for the i-node producer. It is reached (with taking into account the dependences (8) and (12)) as a result of the solution of the unconstrained optimization problem relative to the variable c_{Ri}.

$$B_i(c_{Ri}) \to \max \quad (15)$$

The power reserve optimum price for the producer is determined by the expression

$$c_{Ri} = c_* - \beta_i - 2\gamma_i \cdot P_{i\,max} \, . \quad (16)$$

4. THE STADY RESULTS

Let us examine the task of the power reserves determination for the concentrated EPS, which consist of three thermal plants. The fuel-cost functions for three thermal plants in €/h are given by following functions:

$$C_1 = 500 + 5.3 \cdot P_{g1} + 0.004 P_{g1}^2,$$
$$C_2 = 400 + 5.5 \cdot P_{g2} + 0.006 P_{g2}^2,$$
$$C_3 = 200 + 5.8 \cdot P_{g3} + 0.009 P_{g3}^2.$$

where P_1, P_2 and P_3 are in MW.

The optimization problem must be solved with the following limits of the power generation (P_{gi}) in MW:

$$200 \le P_{g1} \le 450,$$
$$150 \le P_{g2} \le 350,$$
$$100 \le P_{g3} \le 225$$

and the following power reserves limits (R_i) in MW:

$$25 \le R_1 \le 150,$$
$$20 \le R_2 \le 120,$$
$$10 \le R_3 \le 60.$$

In this case the necessary power reserve for the system as a whole must be not less than 110 MW, i.e.

$$\sum R_i \ge 110$$

It is used the marginal approach for the formation of the electric power sale price for I-node each producer $(i = \overline{1,3})$. The fuel-cost functions relative increase for the EPS node will be determined by the following expression:

$$\frac{\partial C_i}{\partial P_{gi}} = \beta_i + 2\gamma \cdot P_{gi} \ . \qquad (17)$$

Let us assume, that the electric power sale price of the i-node producer is more than the marginal price by 10% with taking into account the assumed benefit. thus, in the i node the price of the electric power sold can be calculated according to the expression:

$$c_{gi} = 1.1(\beta_i + 2\gamma_i P_{gi}) \ . \qquad (18)$$

In this case the power reserve price for EPS i-node with taking into account the function (11) will be defined as:

$$c_{Ri} = 0.1(\beta_i + 2\gamma_i P_{gi}) \ . \qquad (19)$$

The summary benefit function B_Σ of the power plants can be formed with consideration the expression (9). The iterations changes for the summary hour benefit function B_Σ with the accepted initial values of the original variables P_{gi} and R_i is given on Fig.1. As a results of the optimization problem research the optimal value of the generation and reserve power for three power plants are obtained with the use of MATLAB program.

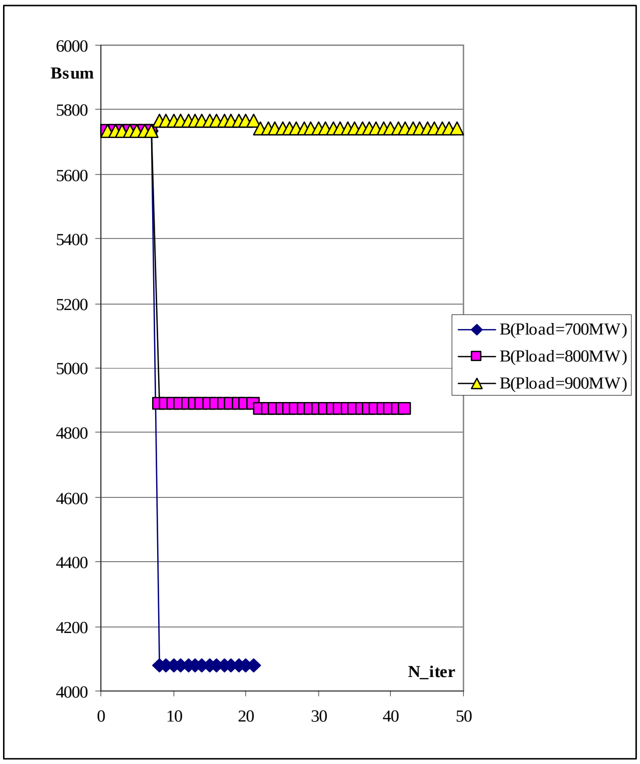

Fig.1. The EPS benefit change in the optimization process depending on three loads

The EPS benefit was calculated for three values of the summary load P_L : 700 MW, 800 MW and 900 MW. For each of the load versions the following optimal values of the variables were obtained:

$B_\Sigma(P_L = 700)$ =4078 Arbitr. units, P_1 =305 MW, P_2 =230 MW, P_3 =165 MW, R_1 =145 MW, R_2 =120 MW, R_3 =60MW;

$B_\Sigma(P_L = 800)$ =4875 Arbitr. units, P_1 =399,5MW, P_2 =235,5MW, P_3 =165MW, R_1 =50,5MW, R_2 =114,5MW, R_3 =60MW;

$B_\Sigma(P_L = 900)$ =5744 Arbitr. units, P_1 =425MW, P_2 =292,6MW, P_3 =182,4MW, R_1 =25MW, R_2 =57,4MW, R_3 =42,6MW.

With one and the same initial data it is increased the value of the EPS expected benefit with the load increase. It is explained by the possibility of the power plants to increase the capacitates of the electric power production for sale. It should be noted, that from a computational point of view the reduction of the summary EPS load facilitates the problem solution of the reserves formation. This fact is evinced by the decrease of the required steps for the optimization iterative process.

5. CONCLUSIONS

1 The creation of the power reserves market is one of the most important conditions of the guaranteeing the reliability of the electric power supply of users and EPS operation.

2 The presence of a sufficient capacitate of the power reserve makes it possible to enlarge the enumeration of the system services under the market conditions.

3 The considered model of the reserve value determination for the individual power producer can be accepted as the basis of the creating the necessary capacitates of the power rotational reserve for EPS.

ACKNOWLEDGEMENT

This work has been partly supported by the European Social Fund within the National Programme, in the framework of the project "Support for the development of doctoral and post-doctoral studies at Riga Technical University".

REFERENCES

[1] Schweppe F.C., Caramanis M.C., Tabors R.D. Evalution of sport price based electricity rates // IEEE Trans. on PAS, vol. PAS – 104, No. 7 , July 1985

[2] Гамм А.З. Компромиссное управление хозяйственно-независимыми электроэнергетическими системами // Изв. РАН. Энергетика, 1993, № 1, с. 46 – 57.

[3] Гамм А.З. Моделирование рынка технических услуг электроэнергетических систем // Изв. РАН. Энергетика, 1997, № 1, с. 116 – 122.

[4] Гамм А.З., Васильев М.Ю. Эскизы моделей рыночных механизмов в электроэнергетике. - Иркутск : ИСЭМ СО РАН, 1999, № 1. – 50 с.

[5] Бартоломей П.М., Летун В.М. Проблема формирования ценовых заявок //- Екатеринбург: Вестник УГТУ-УПИ. Сер. Энергосистема: управление, качество, конкуренция. – 2004, № 12 (42), с. 31 – 35.

[6] Ерохин П.М., Обоскалов В.П. Ценовые заявки на конкурентном рынке электрической энергии //- Екатеринбург: Вестник УГТУ-УПИ. Сер. Энергосистема: управление, качество, конкуренция. – 2004, № 12 (42), с. 52 – 56

[7] Ayuyev B.I., Yerohin P.M., Panikovskaya T.Y. and others. Employment of Approximate Programming for Day-to-Day Management in the Competitive Electric Market//IEEE. Liberalization and Modernization of Power System : Congestion Management Problems. The International Workshop Proceedings by N.I. Voropai and E.J. Handschin. – Irkutsk: Energy Systems Institute, 2003, p. 180 -184.

[8] Кирпикова И.Л., Обоскалов В.П., Черных Ф.Ю. Стратегия поведения производителя электрической энергии в условиях конкурентного рынка заявок //- Екатеринбург: Вестник УГТУ-УПИ. Сер. Энергосистема: управление, качество, конкуренция. – 2004, № 12 (42), с. 60 – 64.

[9] Абызов М.А., Хлебников В.В. Экономические аспекты реформирования российской электроэнергетики // Энергия: экономика, техника, экология, 2004, № 1, с. 18 – 25.

[10] Ерохин П.М. Задачи и технологии оперативно-диспетчерского управления режимами ЕЭС в конкурентно-рыночной энергетике России. Автореферат диссертации на соискание уч.степени докт.техн. наук. – Екатеринбург:УГТУ – УПИ, 2005. - 48 с.

[11] Alomoush M.F. Perfomance indices to measure and compare system utilization and congestion severity of different dispatch scenarios. – Electric Power System Research, vol. 74, issue 2 May, 2005.

[12] Васьковская Т.А. Показатели разницы узловых цен на оптовом рынке электроэнергии // Электричество. – 2007, № 2, с. 23 – 27.

[13] Обоскалов В.П. Надежность обеспечения баланса мощности электроэнергетических систем. – Екатеринбург: ГОУ ВПО УГТУ-УПИ, 2002. -210 с.

[14] Руденко Ю.Н., Чельцов М.Б. Надежность и резервирование в энергосистемах. – Новосибирск : Наука, 1974. -264 с.

[15] Gamm A.Z. Volume II. Market of capacity rezerves in terms of maneuverability and network constraints // Proceedings of the Russian national symposium on power engineering, vol. II. – Kazan, Russia, 2001, p. 281 – 284.

[16] Barkans J., Junghans G. Profit – based optimal scheduling of power plant production //Power and electrical engineering , part 4, vol.20. - Riga, RTU, 2007. –p. 17 – 24.

[17] Блайшчак Гжэгож. Системные услуги в условиях рынка // Электричество, 2001, № 10, с. 7 – 11.

[18] Зильберман С.М., Красильникова Т.Г., Самородов Г.И. Аналитический метод оптимизации балансовой надежности при объединении двух энергосистем // Электричество, 2008, № 2, с. 2 – 9.

[19] Зайченко Ю.П. Исследование операций. – Киев: Вища шк., 1975. – 320 с.