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Some aspects of pricing in the electric power markets

Abstract

Without taking into account system restrictions and tehnical power losses, connected with electric power transmission, all participants of the market sell and buy energy at the consolidated equilibrium price. Accounting the system restrictions the uniform equilibrium price can not be determined. The considered paper illustrates this fact with numerical calculation.

INTRODUCTION

The important part of the organisation of new mutual relations between an electric power system and consumers is working out methods and algorithms of definition of competitive prices of the electric power at different stages of planning, operation and management of development of electropower branch. In world practice there is no uniform approach to definition of optimum models and the algorithms used for efficient control by the markets of the electric power [1-5].

The electric power is a specific product as during each moment of time the balance between manufacture and consumption should be carried out. By working out of mathematical toolkit of definition of competitive prices of the electric power this feature should be considered. For today in world practice some approaches to modelling of competitive prices of the electric power are known [6-11].

The considered work assumes to specify in a certain measure some aspects of pricing in one of two basic models of the existing competitive power markets. The conclusions received on the basis of an illustration of the market and the decision of a problem of pricing on concrete example EPS, are the general and proved.

I. THE BASIC MODELS OF THE POWER MARKETS

Now application of two basic models of realisation of the competitive power markets which essential difference are schemes of consideration of bids, as a rule, find: pool model (fig. 1) and model of bilateral contracts (fig. 2). Each of these models has the features, versions and the respective mathematical description. In each of the models two specific characteristics EPS interfering achievement of an easy approach to transfer are considered: the limited reloading ability and losses of capacity (electric power).

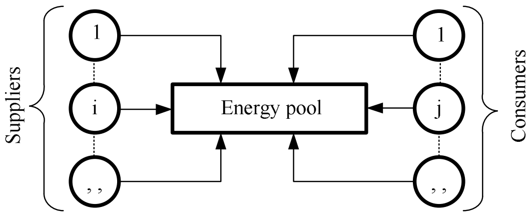

Figure 1. Model a pool .

The model a pool– has arisen because of requirement to spend the process of trade by the electric power on a competitive basis and has received considerable development at stages of introduction of market relations in branch. Participants of the market in the given model co-operate through the market of a cash product (pool) on which demanded volumes of generation on the basis of traditional economic distribution by a finding of a maximum of function of well-being (social wellfare function) are defined.

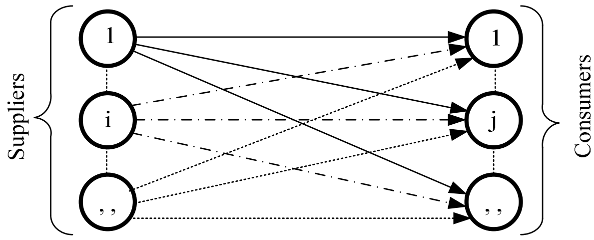

Fig. 2. The model of the bilateral contract.

The basic aspects of pricing for model a pool are based on the theory of central *spotting* prices (the price under condition of an immediate reimbursement cash means) [10]. Hourly *spotting* prices (dollars/kWh) reflect constants and the variable costs connected with development, transport and electric power distribution. In the power pools realised in the different countries, the price changes through the various (established) time intervals and depends, mainly, on bids the electric power purchase/sale. In addition in the central prices range of delivery of the electric power, cost of an overload and technical losses, and also other sizes can be considered. The central price represents the price of sale/purchase of the electric power in *the delivery point,* reflecting local sizes, such as cost of losses and an overload. In the central price usually the following components allocate:

- The price of manufacture of the electric power;
- The price of losses;
- The price of the restrictions which have arisen by transfer.

The model of the bilateral contract (bilateral contracts) is, as a rule, the long-term contract which consists or by carrying out of individual negotiations between the buyer and the seller, or in the market of contracts on delivery. Contract cost is based on bilateral information interchange taking into account market forces and requirements of reliable electrosupply of the consumer, thus centralised optimisation of a mode does not occur. The majority of experts considers, that at the conclusion of contracts it is necessary to carry out optimisation of mode EPS, or the load sharing in an electric power system should be co-ordinated taking into account bilateral contracts. Often two-way deals in foreign practice are represented by the general virtual network of power transactions. Unlike a real network which consists of lines, transformers and other real power objects, allowing to transport the electric power from generating knots to consumers, the virtual network of transactions models power transactions among financial objects (generating units – several blocks or all blocks of a power plant, the energy selling companies and consumers).

The model - the bilateral contract allows participants of the market to hedge (to insure against losses) their risks connected with constant fluctuations of the prices as in the market «for days forward», and in the operative (balancing) market, realised on type a pool. A negative side of long-term contracts is possibility of buying up of treaty obligations other participants of the market that can lead finally to increase in market cost of the electric power.

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In model the bilateral contract is given to consumers direct (open) access to the suppliers chosen by them. And cost of contracts is a trade secret of its proprietors. The parties which have signed a bilateral agreement, are obliged to give the information to ATC and SO only about volumes of contractual conditions. In the conditions of really open access of an energy interchange owing to realisation of agreements between participants of market community regime parametres EPS can change considerably. The mathematical model applied to bilateral contracts and used by services, providing a market fail-safe operation, should consider contributions of separate participants to the valid streams of capacity and energy on communications on the established time interval [1].

For example, at distribution between participants of market community of a payment for technical losses, there are the difficulties connected with a nonlinear dependence of losses from streams of capacity on communications. Besides, the equations of flow separation are nonlinear, meanings of streams and capacity losses are influenced by all set of the concluded bilateral contracts. One of possible ways assumes representation of total technical losses in electric system (ES) in the form of the sum of elements, each of which represents the losses of capacity connected with individual two-way deal. There are the various mathematical models, allowing to present a nonlinear dependence in the form of the sum of separate elements (linear and nonlinear combinations). Other problem connected with realisation of agreements, achievement of a limit of throughput of communication lines. At definition of financial obligations in such situation the participants who mainly have affected achievement of restriction, should pay more. Hence, in the contract price the cost of the electric power defined under the contract (base), cost of losses, cost of reloading ability should be considered.

In the world power markets, as a rule, both models are applied in a combination. It is necessary to notice, that the model a pool is used more often in the operative markets (balancing) and the markets «for days forward» [4]. At the conclusion of long-term contracts (from a week till several years) the model the bilateral contract is more often used. If to assume, that the prices offered by manufacturers rather precisely reflect real cost of manufacture of the electric power the first model allows to reach economic efficiency by selection of the cheapest generating capacities. Thus, it is possible to consider, that within the limits of this model the centralised pricing remains and there is a possibility to optimise an electric mode. The model of agreements does not give possibility to analyze all demands, and also to provide optimum from the point of view of costs a mode in electric system.

II. OPTIMALITY CRITERION OF ENERGY MARKET

Account of the plan of generation, consumption and flow separation in the electric power market is made by means of the decision of a problem of maximisation of social wellfare function which is under construction, proceeding from price bids (PB) of consumers and generating sources, and it is represented as follows:

$$F = \max\left\{\sum_{j=1}^{D} c_{dj}\cdot W_{dj} - \sum_{i=1}^{G} c_{gi}\cdot W_{gi}\right\}, \qquad (1)$$

where c_{dj}, c_{gi} - PB of buyers / of sellers; W_{dj}, W_{gi} - the hourly volumes of consumption of/development declared by subjects the electric power; d - consumption in knot; g - generation in knot; G, D - number generating and loading knots accordingly.

Bids of consumers and suppliers form step curves of the supply and demand which crossing defines the equilibrium price corresponding to equality of volume of a supply and demand $W_{suuply} = W_{demand}$ (fig. 3).

The basic law defining during each moment of time size of manufacture and a current consumption, dependence of capacity on time is $P(t)$. Accountins the results of auction the usual continuous schedule approximate step, thus on some interval of time t is accepted $P(t)$=const. At the established space of time duration 1 hour the electric power volume can be defined as product of meaning of the active power measured on the end of hour for a while $\Delta t = 1$ *hour*.

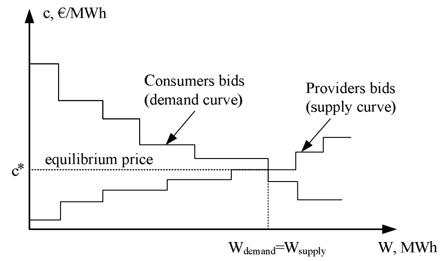

Figure 3. Reception of the equilibrium price at bilateral auction.

Thus, for the space of time equal both for buyers, and for sellers ($\Delta t > 0, \Delta t = const$), criterion function (1) can be transformed to a kind

$$F = \max\left\{\sum_{j=1}^{D} c_{dj}\cdot P_{dj}\cdot\Delta t - \sum_{i=1}^{G} c_{gi}\cdot P_{gi}\cdot\Delta t\right\} = \max\left\{\left(\sum_{j=1}^{D} c_{dj}\cdot P_{dj} - \sum_{i=1}^{G} c_{gi}\cdot P_{gi}\right)\cdot\Delta t\right\} \qquad (2)$$

Meaning Δt always positively also influences only numerical meaning of criterion function in a point of maximum, therefore the finding of optimum meaning of function (4) corresponds to expression

$$F = \max\left\{\sum_{j=1}^{D} c_{dj}\cdot P_{dj} - \sum_{i=1}^{G} c_{gi}\cdot P_{gi}\right\}. \qquad (3)$$

As criterion function for account of results of auction of the electric power expression (5) is used. It allows at decision of an optimising problem to apply the same variable (central capacities), as at accounts of parametres of established modes EPS. Graphically maximum meaning of function of well-being corresponds to the shaded area on fig. 4.

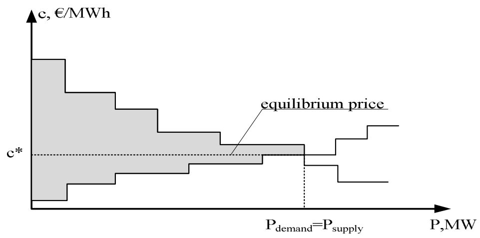

Figure 4. Definition of a total prize of participants of the market.

Unlike bilateral auction at each of the unilateral there are separate components of criterion function. At realisation of unilateral auctions criterion function is presented by the components corresponding to price bids or sellers:

$$F = \min\left\{\sum_{i=1}^{G} c_{gj}\cdot P_{gj}\right\}, \qquad (4)$$

III. REALISATION OF A PROBLEM OF PRICING FOR MODEL A POOL

As it was marked above, realisation of model assumes a pool, that sellers and buyers deal with the intermediary who, knowing or predicting demand for the electric power, solves a question at whom the electric power to take and put into circulation. This decision, depending on the submitted price bids and technological features of influence of generators / consumers on a mode, is defined – who, during what moment of time and, in what volume, should develop and consume the electric power. Here two updatings of the market are possible.

The rigid market functioning on the basis of unilateral auction in which demands of consumers are completely carried out if there is no deficiency of generated capacity.

Let's illustrate this market and a pricing problem on example EPS, consisting of 4 generators and 5 consumers (fig. 5) [11]. Here losses are not considered (we will consider, that they are included in loading).

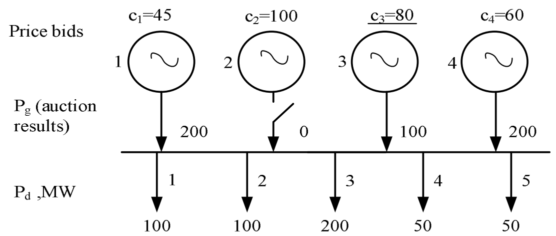

Figure 5. Auction in EPS without regime restrictions on capacity overflows.

In tab. 3.1 capacities of generators and their PB, showing are resulted, on what floor price the generator (as the subject of the market) is ready to sell the electric power.

TABLE 1

The information on generators

Number	1	2	3	4
$P_{gi\max}$, MW	200	200	200	200
$P_{gi\min}$, MW	100	100	100	80
c_{gi} , , €/MWh	45	100	80	60

Here one-stage PB generators (actually they can be multistage) are resulted.

At the first stage "intermediary" (in practice it is the manager of trading system (automatic telephone exchange)) collects price bids of generators and defines demand of the electric power. Let loadings of consumers (received under the forecast or under bids) are accordingly equal, MW:

$$P_{d1} = 100;\ P_{d2} = 100;\ P_{d3} = 200;\ P_{d4} = 50;\ P_{d5} = 50.$$

Thus for total loading consumers (demand) it is equal P_D = 500 MW Ranging available PB generators from minimum to the maximum allows to construct curve "ladder" of offers (fig. 6). At known demand in 500 MW the equilibrium price c_* will be defined on last generator included in structure of sellers. In this case such generator is the generator with number 3. 3 price c_{g3} declared by the generator for the sold electric power equal 80 €/MWh also will define the equilibrium price, i.e. $c_* = c_{g3}$ = 80 €/MWh. Ulith this (minimum market) the price all participants of the market sell or buy the electric power. Besides, such decision has defined at once also structure of the working generating equipment. This result was already illustrated as consequence of unilateral auction in fig. 5. Criterion function for the given generators mix according to (4) matters

$$F = 45 \cdot 200 + 80 \cdot 100 + 60 \cdot 200 = 29000 \text{ €}.$$

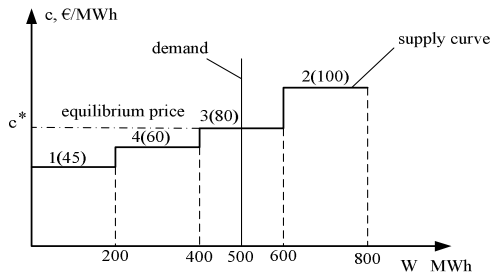

Figure 6. Reception of the equilibrium price in the rigid market.

The second stage of realisation of the unilateral market of the electric power consists in the account of technological constraints. This problem is solved by the system operator (SO), having hierarchical structure according to the accepted dispatch control system.

Let, for example (fig. 7), between the left and right groups of generators and consumers is available a two-chain transmission line (PTL) with restriction on the throughput

Transmission line capacity $P_{l\ admis}$ = 90 MW. In the same drawing the mode which has turned out as a result of spent before auction without throughput concrete PTL is shown. According to this mode specified PTL it appears overloaded, since P_l = 200 MW.

If to consider, that at each generator the underpower, is $P_{gi\min}$ set on the basis of correction mode in resulting dispatching schedule can change both structure of the generating equipment, and loading of generators. In connection with an overload specified PTL, exceeding a permissible limit on 110 MW, the system operator is compelled to make the decision on necessity of correction of a mode. This decision can be subordinated to the following logic.

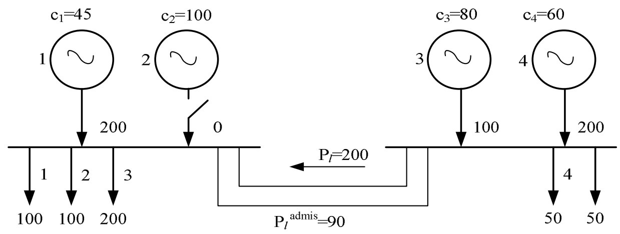

Figure 7. An illustration of impossibility of realization of a mode by results of unilateral auction at the account of limited throughput PTL.

In the right subsystem there is a unique possibility of correction of a mode - to lower generation of 4 h generators on 110 MW and to work with loading in 90 MW. As a result of this decision on considered PTL capacity in 90 MW will be told, that corresponds to a limit on its throughput. The third generator to unload it is impossible, as it already works at the minimum.

In the left subsystem it is impossible to load the first generator as its capacity is already equal maximum (fig. 8). For preservation of balance of capacity as a whole on system it is necessary to include in the market 2 – oh the generator with the most expensive electric power and to appoint to it generation P_{g2} = 110 MW.

Thus, in connection with mode correction the uniform equilibrium price for both subsystems cannot be established. In the given example in the left subsystem the central price of the electric power is accepted equal 100 €/MWh (the price of the most expensive 2nd generator), and the central price in the right subsystem is accepted equal 60 €/MWh (the price of 4th generator) as because of external restriction without equipment switching-off cheaper 4th generator is loaded not completely. Meaning of criterion function (4) thus

$F = 45 \cdot 200 + 100 \cdot 110 + 80 \cdot 100 + 60 \cdot 90 = 33400$ €.

That exceeds the previous meaning 29000 € (received without technological constraints).

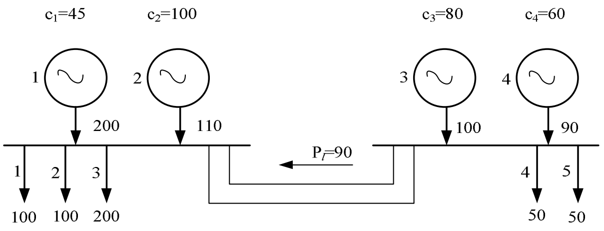

Figure 8. Influence of technological constraints of pricing in EPS.

The received result testifies that the account of specificity of the electric power as a product does not allow to consider concept of the equilibrium price as only price in the electric power market considering presence of set of technological constraints at functioning EPS.

The elastic market functions on the basis of bilateral auction in which pricing in EPS influence also PB buyers of the electric power (fig. 3). In the elastic market at the first stage are separately ranged PB generators (on price increase) and buyers (on decrease). Crossing of these two part-linear functions defines the optimum decision (the equilibrium price),

Corresponding to equality of volume of a supply and demand: $W_{\sup ply} = W_{demand}$.

By consideration of model of contractual relations between sellers and the buyers, established on the basis of bilateral contracts the volume and the price of delivery of the electric power will be co-ordinated. In electric power industry it is necessary to co-ordinate these bilateral agreements at the same intermediary (automatic telephone exchange) and SO which considers arising transit of capacity and its influence on a mode and capacity losses. It defined that neither the seller (generator), nor the buyer (consumer) do not exist independently as it is possible in other spheres of a social production when mutual deliveries and reception of a product do not break the general "know-how" of a product at other subjects.

IV. CONCLUSIONS

1. A condition formation of the uniform equilibrium price for the electric power fairly only in the absence of any technological constraints on mode parametres. The equilibrium price is defined under the price demand of last generator included in structure of sellers.

2. In the presence of the technological constraints influencing pricing, in different knots EPS the different central prices are formed. The electric power price in knots will be defined on the basis of the sold (bought) volumes and overflows.

REFERENCES

[1] Shweppe F.C. Spot pricing of Electricity / F.C. Shweppe, M. Caramanis, R. Tabors. – Boston: Kluwer Academic Publishers, 1988.

[2] Makkonen S., Lahdelma R. Analysis of Power Pools in the Deregulated Energy Market through Simulation // Proceedings of the 32nd Hawaii International Conference on System Sciences, 1999.

[3] Zimmerman R.D., Bernard J.C., Thomas R.J., Schulze W. Energy Auctions and Market Power: An Experimental Examination // Proceedings of the 32nd Hawaii International Conference on System Sciences, 1999.

[4] Transmission Loss Allocation: A Comparison of different Practical Algoritms / A.J.Conejo, J.M. Arroyo, N. Alguacil, A.L. Guijarro // IEEE Transactions on Power Systems. 2002, vol.17, No.3.

[5] Stoff S. Power Systems Economics: Designing Markets for Electricity (J. Wiley and Sons, 2002). – 468 p.

[6] Hogan W. Contract networks for electric power transmission // Energy and Environmental Policy Center, Harvard University , September 1990.

[7] Post D.L. Application of Auctions as a Pricing Mechanizm for the Interchange of Electric Power / D.L. Post, S.S. Coppinger , G.B. Sheble // IEEE Transactions on Power Systems. 1995, vol.10, No.3.

[8] Singh H., Hao S., Papalexopoulos A. Transmission congestion management in competetive electricity market //IEEE Trans. on PWRS, 1998. –Vol. 13, No. 2. – pp. 672-680.

[9] Stamtsis G. C., Christiansen J. Erlich I. Evaluation of power Systems Congestions Using Nodal Price Analysis // MEPS ' 02 , Wroclaw, Poland, September 11 – 13 , 2002 .

[10] Sheble Gerald B. Computational auction mechanisms for restructured power industry operation / Gerald B. Sheble. –Boston (London): Kluwer AcademicPublishers: 2002.

[11] Bartolomey P.I., Panikovskaya T.J. Optimization of power system regims. – Eкaterinburg: USTU- UPI, 2008. – 164 p.

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