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Possibility of Controlling Nonregulated Prices in the Electricity Market by Means of Varying the Parameters of a Power System

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Abstract—This paper offers a new approach to the analysis of price signals from the wholesale electricity and capacity market that is based on the analysis of the influence exerted by input data used in the problem of optimization of the power system operating conditions, namely: parameters of a power grid and power-receiving equipment that might vary under the effect of control devices. It is shown that it would be possible to control nonregulated prices for electricity in the wholesale electricity market by varying the parameters of control devices and energy-receiving equipment. An increase in the effectiveness of power transmission and the cost-effective use of fuel-and-energy resources (energy saving) can become an additional effect of controlling the nonregulated prices.

Keywords: electricity market, price for electricity, optimization, control

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The wholesale electricity and capacity market with competitive pricing has operated in Russia since 2003. Electricity and capacity are special commodities sold and purchased within the framework of the United Energy System of Russia within the limits of the common economic space of the Russian Federation. For a power system, sale of capacity implies obligations on maintaining the readiness to deliver power into a grid in a prearranged amount. In the electricity market, the demand for consumption of electricity with the most efficient loading of power plants on the basis of operating conditions being implemented is provided. In the capacity market, the long-term reliability of electricity supply with the lowest possible costs is provided. Market participants are large suppliers and buyers of electricity and capacity. To the former category belong owners (lessees) of power-generating equipment with the installed capacity no lower than 5 MW. To the latter category belong electricity-sales and electricity-supplying organizations and large consumers with the connected capacity of no lower than 20 MVA. Organizations engaged in import and export operation are both suppliers and purchasers of electricity and capacity at the same time.

The interaction between market participants is provided by organizations that are part of the technological and commercial infrastructure. The technological infrastructure provides power transmission through power grids and the operative-dispatching power control. The commercial infrastructure performs, on the basis of self-regulation, the functions on organizing an efficient system of wholesale and retail trade in electricity and capacity, makes financial calculations, organizes the system for measurement and gathering of information about the actual production and consumption of electricity and capacity by participants of the wholesale market.

The economic relationships in the wholesale electricity and capacity market are based on the competitive (nonregulated) prices. Such prices provide price signals that are needed for developing power generation and power grids and for efficient consumption of electricity. In works [1–4], an effect of devices that control the parameters of components of a power system on the nodal prices for electricity has been studied. In the present paper, we propose to use price signals and to provide a market participant with an efficient tool for controlling nonregulated prices for electricity in the medium term. We show the possibility for controlling nodal energy prices by means of varying the parameters of a power grid and power-receiving equipment.

Let us now consider the feasibility of such control on the simple example of a power system described in the illustrative example 9.7 [5] and consisting of three nodes (Fig. 1). This scheme includes three transmission lines, two power-generating nodes *1*, *2*, and a load node *3*. Power line resistances are the following: $\underline{Z}_{12} = 10 + j20\ \Omega$; $\underline{Z}_{13} = 15 + j30\ \Omega$; $\underline{Z}_{32} = 10 + j25\ \Omega$. Node *1* is

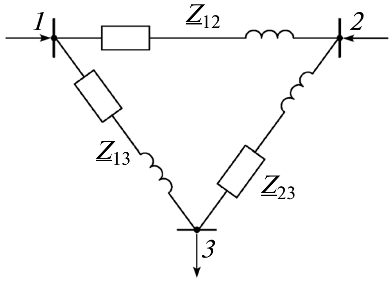

Fig. 1.

taken to be slack one, the voltage $\underline{U}_1 = 115$ kV. The load in node *3* is $\underline{S}_3 = 46.188 + j23.084$ MVA.

Let us suppose, in addition, that the price for power generation in the generation nodes is c_1 = 1000 RUR/(MW h), c_2 = 800 RUR/(MW h). We suggest that calculations are made for each hour of the day and the amounts of electricity are numerically equal to the amount of capacity. Obviously, loading of the power-generating equipment in the power-generating node *2* is economically more advantageous, because the price for electrical energy generation is lower in this node. However, depending on the state of the network infrastructure, for example, because of limitations on power transmission imposed by the operating conditions of a power grid, power generation in the node *1* might be needed.

Let us suppose that there exists some limitation as to the active power transmission in the line *2–3*, and $P_{s\_\max}$ = 25 MW. The presence of such limitation makes load shedding of the power-generating equipment in node *2* and loading of the power-generating equipment in node *1* necessary. There is a need for selecting optimum power system operating conditions by means of minimizing the objective function.

$$c_1P_1 + c_2P_2 \longrightarrow \min. \tag{1}$$

Limitations used in the optimization problem are nonlinear equations of power system operating conditions and limitations imposed on the line *2–3*. The results of the optimization calculation are the following. Power generation in nodes *1* and *2* is: $\underline{S}_1 = 24.82 + j11.92$ MVA; $\underline{S}_2 = 22.74 + j14.24$ MVA. The voltage in nodes *2* and *3* is: $\underline{U}_2 = 114.65\angle -0.16°$ kV; $\underline{U}_3 = 109.26\angle -2.33°$ kV. Power flows in the initial nodes of the line are: $\underline{S}_{12} = 2.27 + j0.86$ MVA; $\underline{S}_{13} = 22.55 + j11.06$ MVA; $\underline{S}_{23} = 25.00 + j15.09$ MVA.

When the Lagrange method of multipliers is used for solving the optimization problem, additional variables—Lagrange multipliers—are introduced into this problem for each limitation. These multipliers for nonlinear equations of power system operating conditions for active power characterize the magnitude of the change in the values of the object function as a result of minor change in the active load in a certain node, and they are considered as prices for electricity. For power generating nodes *1* and *2*, as long as a network-imposed limitation is active, these multipliers, and, correspondingly, prices for electricity will be 1000 and 800 RUR/(MW h). The Lagrange multiplier for the limitation to the active power balance in node *3* can be viewed as a price for electricity for a consumer, which is 1379.98 RUR/(MW h).

A similar problem is being solved in the wholesale electricity market on a day-ahead basis, with the difference that price bids submitted by electricity buyers are not considered in the present work. The load in node *3* is prearranged by a fixed amount of capacity. In such a case, the minimization of the object function (1) is the same as the maximization of the welfare function [6].

Let us now perform a number of optimization calculations at various values of the inductive reactance X_{13} from 20 to 40 Ω of the power line *1–3* and consider its effect on the price for electricity in node *3*. An increase in X_{13} would bring about an increase in the total resistance of power line *1–3*. This, in turn, would result in the reduction of the share of the total power flow from power-generating nodes through this line, and in an increase of the share of the power flow through line *2–3*, which would make the operating conditions heavier, because there was imposed a limitation on the maximum permissible flow of active power in line *2–3*. As a result, the power generation in nodes *1* and *2* would be redistributed: it would decrease in node *2*, while it would increase in node *1*; therefore, the values of object function (1) and a price for a customer would increase. When X_{13} decreases, the reverse situation is observed. The results of the obtained dependences of a price in node *3*, loading of power-generating capacities in nodes *1* and *2*, and the object function (1) on the parameter X_{13} are shown in Fig. 2.

Thus, when parameter X_{13} decreases, an effect is observed both for a consumer in the form of reduced price for electricity and for the market as a whole in the form of a decreased value of the object function, which implies the more economical consumption of fuel-and-energy resources.

Let us connect a shunt with the susceptance B_{shunt} to node *3* and perform the second series of optimization calculations at various values of B_{shunt} from -4×10^{-3} S to 4×10^{-3} S. The results of this series of calculations reveal more complicated dependences (Fig. 3) Thus, the power generation in nodes *1* and *2* and the object function (1) within the range of variation of B_{shunt} exhibit distinct minima (maxima). It should be noted that the price decreases when the shunt resistance is of reactive nature. This is an indication that the price for electricity for a consumer depends on a power factor of the power-generating equipment, and the higher the power factor, the lower the price for electricity. If the reactive power undergoes reversal of

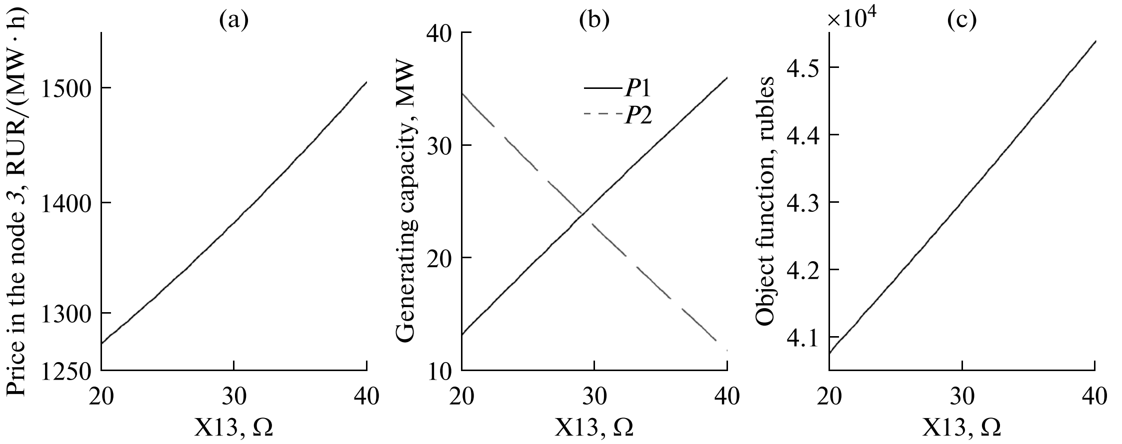

Fig. 2.

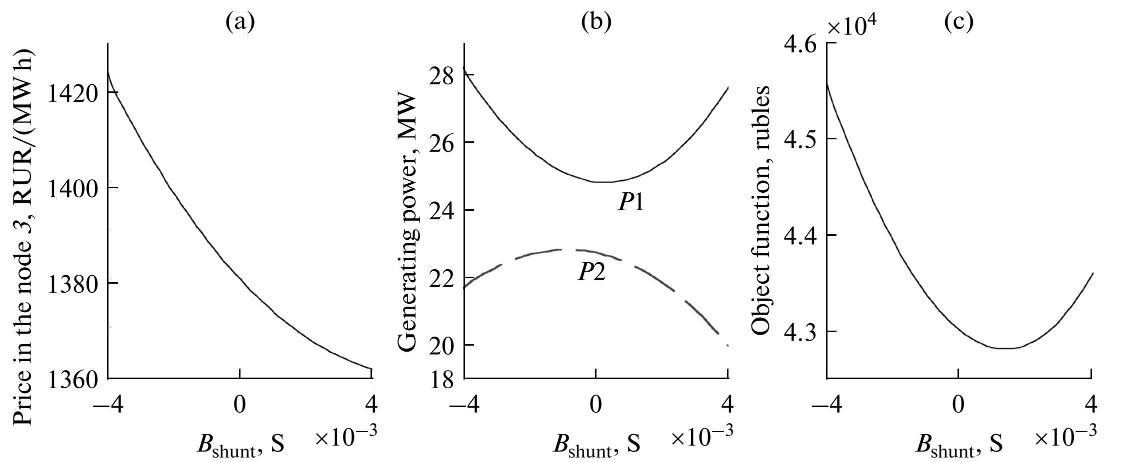

Fig. 3.

its sign in the load node, this will result in even greater reduction in the price for electricity, until the price minimum. The further increase in the parameter B_{shunt} will bring about an increase in the price for electricity.

From the results of this series of calculations, we can see that prices for electricity that are formed in the wholesale market offer incentives for reactive power compensation on the part of consumers of electrical power.

To perform an analysis of the location of network control devices in large power systems in order for finding a minimum price for electricity, it may prove useful to present the dependences obtained in an analytical form. Such approach is used for analyzing the power system operating conditions [7]. It can also be used for analyzing the effect of parameters of network and energy-receiving equipment on the results of optimization of power system operating conditions.

The dependence of a price for electricity on a parameter being considered in this example is well approximated by the function

$$f(x) = \frac{ax^2 + bx + c}{dx^2 + ex + 1} \tag{2}$$

or

$$f(x) = \frac{ax + b}{cx^2 + dx + 1},$$

where x is a parameter being varied; a, b, c, d, and e are the constants which is easy to determine by means of five (four) optimization calculations at various values of x.

By using the function (2) for the second series of optimization calculations, after determining the constants, it is easy to find a minimum of the function $f(x)$, which is achieved in the point $x = 5.5 \times 10^{-3}$ and is equal to 1359.9. As can be seen from Fig. 3a, calculated price approaches particularly to this value.

The results obtained in the present paper can be used in a similar way for power generating nodes as well.

CONCLUSIONS

It has been demonstrated that the price for electricity, which is determined as a result of optimization of power system operating conditions, depends on the parameters of a power grid and power-receiving equipment. Owing to the use of controlling power grid and compensating devices it becomes possible to control the prices in the wholesale electricity market. It has been shown that the control of nonregulated prices in the wholesale electricity market might further increase the effectiveness of electric power transmission and provide more economical use of fuel-and-energy resources (energy saving.)

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