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Application of a systematic approach to improving the efficiency of power supply modes of the Republic of Crimea

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Abstract. The structure of the region's energy supply is considered, the characteristics of all the major groups of electricity producers in the region, including thermal power plants, mobile gas turbine power plants, renewable energy sources, backup power sources, are presented. As tariffs in the transport problem under consideration, depending on the purpose of the calculations, it is proposed to use the averaged actual values in a given period of time according to the energy supplying organizations (the purpose of the calculations is to reduce the cost of production and transportation of electricity), and also conditional qualitative assessments - "fines" (The goal is to improve the environmental and reliability of the system as a whole). The influence of the generated power of solar power plants on the operation modes of the power system of the Crimea is investigated. A methodology has been developed to optimize the production of solar power plants that affect the reliability and quality of power supply. The calculation of different scenarios of energy supply of the Crimea carried out, including at peak and average modes of power consumption, with different variants of solar activity, the time of year, taking into account and without taking into account the energy sources under construction, repair works of sources in the off-season. Based on the results of the calculations, conclusions are made about the reliability of the power system in the region under different scenarios of power supply, as well as the need to use the power bridge for the flow of electricity from the mainland in both directions.

1. Introduction

Linear mathematical models to optimize the development of electric power systems in order to minimize the total reduced estimated costs for a set of years of the calculation period with power limitations of different types of power plants, the capacity of intersystem power lines, the implementation of the effect of combining electric power systems are considered in the works [1-2 etc].

Mathematical modeling of electric power consumers in the optimization of electric power systems development using the method of multi-criteria analysis of solutions are given in the works of Trufanov V. [3-4].

Foreign developments in the field of power system optimization were carried out in two directions [5]: 1) creation of models for global optimization of the structure of electric power systems in the dynamics of their development using linear programming methods; 2) development of models for economic evaluation and comparison of predetermined options for the development of electric power



systems. In foreign literature, the problem of linear programming in relation to the optimization of modes of energy transportation in power systems is considered in the monograph James A. Momoh [6] and the works of other authors [7-8].

For the implementation of the second direction [5], as a rule, specialized private models were used to solve individual problems arising in the justification of the development of energy systems: forecasting of loads, determining the timing of new generating capacity under the conditions of reliability of power supply, optimization of power lines, optimization of load distribution, calculation of total costs, etc. Game-theoretic models of generation development [9-10] and electric network [11-12] are considered. The problems of forecasting and modeling the load of consumers, the reliability of the power system are considered in [13-14]. In particular, in [14] the authors R. Scan, H. Rudnick, etc. cite the application of the Monte Carlo method to optimize the power system, modeling reliability, failures in the transmission of electricity in time dynamics. The issues of solving extreme problems in the power industry in order to reduce costs, taking into account reliability, are also considered in [15-16].

Methods and algorithms of dynamic programming for optimizing the structure and parameters of power systems are considered in the works of James A. Momoh [6] and [17-19]. Modeling of operating modes of renewable energy sources, in particular wind and solar power plants, depending on natural factors, as well as issues of reliability of renewable energy sources are considered in the works of foreign authors [20-23]. In particular, [22-23] discuss the optimization of the ratio of wind and solar power plants operating in a unified power system.

Issues of modeling of power systems with renewable energy sources are also discussed in the works of domestic authors [24-25, etc.]. The work of scientists of the Institute of energy systems named after L. A. Melentyev, Marchenko O. et al. [24] provides a mathematical model for the study of the economic efficiency of the power system with renewable energy sources of any configuration, including the technology of transformation, transport and energy storage. In the work of scientists of Tomsk Polytechnic University Mikhilchenko S. et al. [25] is an adaptive algorithm of extreme power control in the solar energy system.

Methods and algorithms for improving energy efficiency of power supply systems are also considered in [26-27].

Uninterrupted supply of electricity to the territory of Crimea is a strategically important task for the development of the region. With the actual accession of Crimea to Russia, the reliability of power supply systems has decreased due to Crimea's energy dependence on Ukraine. To increase the energy independence of the Crimea on the Peninsula introduced new power, in particular Tauride and Balaklava TPP with design capacity of 470 MW each.

Currently, the region's electricity producers can be divided into the following main groups:

- CHPP – combined heat and power plant;
- MGTPP – mobile gas turbine power plants;
- RES – renewable energy sources, including SES (solar power plants) and WPP (wind power plants);
- RPS – redundant power supply;
- Power bridge (cable and air power lines and substations built to connect the Crimean energy system to the UES of Russia (UES of the South).

The total capacity of thermal power plants is 306 MW (including the Tauride and Balaklava TPP – 1246.34 MW), mobile gas turbine power plants – 396.1 MW, renewable energy sources – 388.5 MW, reserve power sources – 121 MW.

It should be noted that in the summer the produced power of SES, under adverse natural conditions, can be reduced by almost 90%, while a significant part of the generating capacity of thermal power plants is in the maintenance outage.

The total maximum allowable flow (hereinafter-MAF) of the energy bridge is 810 MW.

2. Mathematical model of power system optimization

The task is to optimize the energy system in order to reduce the cost of production and transmission of electricity, taking into account the reliability and environmental friendliness of the power supply system. The initial data in the problem are dynamic values, which allows us to obtain a solution (the required power of different power producers) in different periods of time depending on the needs of consumers.

In this case, the objective function is the minimum cost of production and transmission of energy:

$$c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + c_5x_5 + c_6x_6 \rightarrow \min \quad (1)$$

In this statement of the task, the initial stage did not include the breakdown of consumers into groups of the population and legal entities, which will be taken into account in further studies. All coefficients and variables are dynamic values and change over time.

The system of limitations has the form:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \geq N_{cons}, \quad (2)$$

$$x_1 \leq x_{1max}, \quad (3a)$$

$$x_2 \leq x_{2max}, \quad (3b)$$

$$x_3 \leq x_{3max}, \quad (3c)$$

$$x_4 \leq x_{4max}, \quad (3d)$$

$$x_5 \leq x_{5max}. \quad (3e)$$

In the objective function (1) and the system of restrictions (2,3), the following designations are adopted: N_{cons} - maximum power consumption (MW), power producers (MW): x_1, x_{1max} – actual and maximum CHPP capacity; x_2, x_{2max} – actual and maximum MGTPP capacity; x_3, x_{3max} – actual and maximum RES capacity; x_4, x_{4max} – actual and maximum RPS capacity; x_5, x_{5max} – actual and maximum Power bridge capacity; x_6 – capacity shortage is required to meet condition (2). Tariffs (conditional units per MW of energy): c_1 – tariff for production and transmission of energy from CHPP; c_2 – tariff for production and transmission of energy from MGTPP; c_3 – tariff for production and transmission of energy from RES; c_4 – tariff for production and transmission of energy from RPS; c_5 – tariff for production and transmission of energy from Power bridge; c_6 – penalty tariff from capacity shortage (obviously large value).

Tariffs in the proposed formulation of the problem can be of two types, depending on the purpose of the calculations:

- averaged actual values in a given period of time according to the data of energy supplying organizations (the purpose of the calculations is to reduce the cost of producing and transporting electricity);
- conditional qualitative assessments – "fines" (the goal is to increase the environmental friendliness and reliability of the system as a whole), i.e. the lower the value of the tariff (fine) c_i so for the power system this i – th source is more qualitatively preferable and vice versa.

If the result of solving this problem (1) - (3) capacity shortage $x_6 > 0$ so there is a capacity shortage in the amount of x_6 , if $x_6 = 0$ – capacity shortage is missing.

3. Results

In the computational experiment, the tariffs were given as qualitative estimates - "fines" (table 1), where the minimum tariff is adopted for renewable energy sources as the most environmentally friendly and promising sources.

Table 1. Qualitative estimates of tariffs.

Tariff type	Tariff value
Tariff for production and transmission of energy from CHPP (c_1)	2
Tariff for production and transmission of energy from MGTPP (c_2)	4
Tariff for production and transmission of energy from RES (c_3)	1
Tariff for production and transmission of energy from RPS (c_4)	5
Tariff for production and transmission of energy from Power bridge (c_5)	3
Penalty tariff from capacity shortage (c_6)	10

Taking into account the fact that in 2017 many-year energy consumption peaks were reached in the Crimea: 1,427 MW - winter maximum and 1,249 MW - summer maximum [29], the following design scenarios are suggested, taking into account the growth of peak consumption (up to 10% in 2019) from achieved in 2017:

1. Off-season. Repairs of CHPP and MGTPP (capacity of heat sources is reduced by 50% of the maximum capacity). Minimal solar activity. Load of consumption - 1,250 MW. Without taking into account the TPP under construction.

2. Summer period. Maximum solar activity. Peak demand -1374 MW. Without taking into account the TPP under construction.

3. Winter period. Minimal solar activity. Peak demand -1570 MW. Without taking into account the TPP under construction.

4. Maximum solar activity. Peak demand is 1570 MW. Maximum capacity MGTPP, CHPP and TPP.

5. Maximum solar activity. Low consumption load - 1000 MW. Maximum capacity MGTPP, CHPP and TPP.

Initial calculation data and calculation results are given in table 2, where the maximum capacity of the RPS is 50% of the installed capacity, the capacity of the CHPP and MGTPP are set taking into account repair work, RES depending on the simulated natural factors in different periods.

In implementing the program module for solving this problem, the existing experience of applying a systematic approach to the development of software in the field of energy efficiency of energy supply systems was taken into account [28-29].

Table 2. Calculation of different energy supply scenarios.

Number of scenarios	Consumption load, MW	Maximum power sources for the scenario, MW	Actual available power of sources, MW	Capacity shortage of power system, MW
1	1250	CHPP – 153, MGTPP – 198, RES – 20, RPS – 60, Power bridge – 810	CHPP – 153, MGTPP – 198, RES – 20, RPS – 60, Power bridge – 810	9
2	1374	CHPP – 306, MGTPP – 396, RES – 230, RPS – 60, Power bridge – 810	CHPP – 306, MGTPP – 28, RES – 230, RPS – 0, Power bridge – 810	0
3	1570	CHPP – 306, MGTPP – 396, RES – 20, RPS – 60, Power bridge – 810	CHPP – 306, MGTPP – 396, RES – 20, RPS – 38, Power bridge – 810	0
4	1570	CHPP – 1246, MGTPP – 396, RES – 230, RPS – 60, Power bridge – 810	CHPP – 1246, MGTPP – 0, RES – 230, RPS – 0, Power bridge – 94	0

5	1000	CHPP – 1246, MGTPP – 396, RES – 230, RPS – 60, Power bridge – 810	CHPP – 770, MGTPP – 0, RES – 230, RPS – 0, Power bridge – 0	0
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4. Conclusion

1. The first scenario showed the dependence of the power system and consumers on RES. There was a disconnection of the consumer load of about 9 MW. The reason for this situation was the lack of generating capacity due to repairs, restrictions on the flow to the power bridge, adverse weather factors.

2. The second scenario showed that under favorable weather conditions on a sunny day and, accordingly, the presence of additional generation of RES in the operational planning and management of the power system mode, there was no shutdown of the load of consumers. At the same time there is a small power reserve.

3. The third scenario showed the dependence of the power system and consumers on RES. There is no disconnection of the load of consumers, but almost all available power generation is involved. The reason for this situation was the peak load of consumers, restrictions on the flow to the power bridge, adverse weather factors.

4. The fourth scenario - with favorable weather conditions on a sunny day and the introduction of new CHPP capacity, it is possible to refuse expensive MGTPP, RPS, even at peak electricity consumption.

5. Fifth scenario - under favorable weather conditions on a sunny day, when new CHPP capacities are commissioned, it is possible to abandon expensive MGTPP, RPS. In this case, it is possible to supply electricity to the mainland on a power bridge of about 476 MW.

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