Analysis of the adjustment range in the ups russia and ways of its improvement in the creation of new power facilities

S S Beloborodov¹, A A Dudolin²

¹ NP "Energy Efficient City", Moscow, Russia, 105094, Semenovskaya nab, d. 2/1, p. 1
² National Research University "Moscow Power Engineering Institute"
Russia, 111250 Moscow, Krasnokazarmennaya, 14

Email:dudolinaa@mpei.ru

Abstract. In the absence of an effective technological possibility for the storage of electricity in industrial volumes, consumption and production of electrical energy are carried out simultaneously. The ability to generate cover the unevenness of the daily schedule of consumption provides a balance of power system parts, leads to the minimization of network infrastructure costs. This article represents the analysis of the results for balancing certain parts of the UPS Russia, based on the methodological approach described below. Volume of "basic" electrical energy consumption specifies requirements for the structure of generating capacity. Reducing the share of "basic" consumers, including by the construction of its own "base" generation, leads either to an increase in the depth of discharge of generating capacities in the power system, or to the necessary shutdowns of generating equipment at night. Performed calculations showed non-optimal placement of the "base" generation in the Russian Federation. The proposed method allows you to determine the presence and absence of the adjustment range in the power system as a whole or in its individual parts, avoid errors in the placement of generating capacity in the Russian Federation, including nuclear power plants, heat supply units, "green" generation, optimize the cost for the construction of the network infrastructure.

1. Introduction
In view of the lack of an effective technological capacity for storing electricity in industrial volumes, consumption and production of electric energy is carried out simultaneously. Hence, the structure of consumption of electric energy (power) should determine the structure of generating capacities. The ability of generation to cover the unevenness of the daily consumption schedule ensures the balancing of individual parts of the power system, leading to a minimization of costs for the network infrastructure. This article presents the results of the analysis of the balance of individual parts of the Unified Energy System of the Russian Federation, carried out on the basis of the methodical approach described below. The volume of "basic" consumption of electrical energy determines the requirements for the structure of generating capacities. The greater the proportion of electricity consumption in the basic mode, the less the regulatory range in the power system is required. Decrease in the share of "basic" consumers, including by building their own "base" generation, leads either to an increase in the depth of unloading...
of generating capacities in the power system, or to the need for shutdowns of generating equipment for the night.

To determine the ability of the generating equipment to cover the unevenness of the daily consumption schedule, we introduce the coefficient \( K \), calculated as the ratio of the daily minimum of electric power consumption minus the base generation power (nuclear power plant, heating, wind generation (reduces the share of base generation)) to the difference in the daily maximum of electric power consumption and the base Generation.

\[
K = \frac{P_{\text{min}}^{\text{con}} - \sum P_{\text{bas}}^{\text{gen}}}{P_{\text{max}}^{\text{con}} - \sum P_{\text{bas}}^{\text{gen}}}
\]

where:

- \( P_{\text{min}}^{\text{con}} \) - Minimum daily electrical power consumption;
- \( P_{\text{max}}^{\text{con}} \) - Maximum daily electrical power consumption;
- \( \sum P_{\text{bas}}^{\text{gen}} \) - Electric power of base generation.

For example, if the ratio of the daily minimum to the daily maximum consumption is 50%, then in the absence of a "basic" generation, a power plant with \( P_{\text{max}} = 100\% \) and \( P_{\text{min}} = 50\% \) will be able to provide power to consumers without switching off part of the generating equipment for the night.

As sources of "basic" generation, the following energy objects are listed in Table 1.

| Type of power station | Justification |
|-----------------------|---------------|
| NPP                   | \( P_{\text{min}} \) Technological NPP based on the data of the System Operator is 99.4% - 99.7% of the technological maximum. The adjustment range is only 0.3% to 0.6% (3-6 MW per 1000 MW unit). Thus, under normal operating conditions of the UES of Russia, nuclear power plants do not provide an adjustment range. |
| Thermal generation of CHPP | High fuel efficiency of thermal turbines is achieved only when operating in cogeneration mode. The production of electric energy in T-turbines in the condensation mode is inefficient. Thus, T-turbines must operate exclusively in the heating mode. Loading of T-turbines in the condensation mode means that the structure of generating capacities does not conform to the structure of consumption. |
| Wind generation       | The production of electric power in wind power plants is of a probabilistic nature. If there is a priority, the load of wind generators in the hours of the daily minimum reduces the amount of basic consumption available for the rest of the generation. |

Figure 1 shows the effect of "basic" generation on the requirements for the regulatory range of the remaining part of the power plants. The required adjustment range of the remaining generating capacities after the loading of the "base" generation (NPP, Heating, Wind generation) exceeds 50%.
Figure 1. Effect of "basic" generation on the requirements for the regulatory range of the remaining part of the power plants.

To operate the included generating equipment without stopping for the night, the ratio of their technical (technological) minima (without taking into account the "base" generation) to the technological maxima should be lower than the coefficient $K$.

$$
K \geq \frac{\sum P_{min}^{gen}}{\sum P_{max}^{gen}}
$$

where:

$\sum P_{min}^{gen}$ - The sum of technical (technological) minimums of generation (without taking into account the base generation)

$\sum P_{max}^{gen}$ - The sum of technological maximums of generation (without taking into account the base generation)

If the ratio of the technical (technological) minimum to the technological maximum of the included generating equipment, with the exception of the base generation, exceeds the $K$ coefficient, either a part of the generation must be switched off for the night or the flow to other parts of the unified power system having reserves of the control range.

2. Analysis of balanced power systems

Below are the results of calculating the $K$ coefficient for each IES of the Russian Federation under the condition that only the power units of nuclear power plants are referred to the "basic" generation. Calculations are completed for the winter period 2014/2015 and summer period 2014 on the basis of the initial data [1,2].

2.1. IES North-West

Figure 2 shows the calculated $K$ coefficient for the winter of 2014/2015.
Figure 2. Level of the minimum daily load of the station (without NPP) IES of North West (winter of 2014/2015).

In the winter period 2014/2015, the coefficient $K$ for thermal and hydrogeneration was in the range from 55% to 67%. The actual value of the ratio of the technological minimum to the technological maximum exceeded 70%. Thus, the UES of the North-West is not able to cover the unevenness of the daily consumption schedule without flowing beyond the boundaries of the ECO. The value of the coefficient $K$ will decrease by 6% with an increase in the base generation in the IES of the North-West in the winter period by 1000 MW. Figure 3 shows the calculated coefficient $K$ data for the summer of 2014.

Figure 3. Level of the minimum daily load of the station (without NPP) IES of North West (summer of 2014).

In the summer period of 2014 the coefficient $K$ for thermal and hydrogeneration was in the range from 30% to 50%. The actual value of the ratio of the technical (technological) minimum to the technological maximum exceeded 58%. Thus, the UES of the North-West is not able to cover the unevenness of the daily consumption schedule without flowing beyond the boundaries of the ECO. The value of the coefficient $K$ will decrease by 25% with an increase in the base generation in the IES of the North-West in the summer period by 1000 MW.
2.2. **IES Center**

Figure 4 shows the calculated K coefficient for the winter of 2014/2015.

![Figure 4](image)

**Figure 4.** Level of the minimum daily load of the station (without NPP) IES of the Centre.

In the winter period 2014/2015, the coefficient K for thermal and hydrogeneration was in the range from 54% to 65%. The actual value of the ratio of the technological minimum to the technological maximum exceeded 62%. Thus, UES of the Center is not capable of independently covering the unevenness of the daily consumption schedule without overflows outside the ECO. The value of the coefficient K will decrease by 2% with an increase in the base generation of 1000 MW in the UES of the Center in the winter.

Figure 5 shows the calculated coefficient K data for the summer of 2014.

![Figure 5](image)

**Figure 5.** Level of the minimum daily load of the station (without NPP) IES of the Centre (summer of 2014).

In the summer period of 2014, the coefficient K for thermal and hydrogeneration was in the range from 37% to 54%. Thus, UES of the Center is not capable of independently covering the unevenness of the daily consumption schedule without overflows outside the ECO. The value of the coefficient K
will decrease by 6% with an increase in the base generation of 1000 MW in the UES of the Center in the summer.

2.3. IES South

Figure 6 shows the calculated K coefficient for the winter of 2014/2015.

In the winter period 2014/2015, the coefficient K for thermal and hydrogeneration was in the range from 60% to 70%. Thus, IES of the South is able to cover independently the unevenness of the daily consumption schedule without overflows outside the ECO. The value of the coefficient K will decrease by 5% with an increase of 1000 MW of base generation in the UES of the South in the winter.

Figure 7 shows the calculated coefficient K data for the summer of 2014.

In the summer period of 2014, the K coefficient for thermal and hydrogeneration was in the range from 50% to 62%. Thus, the UES of the South is not capable of independently covering the
unevenness of the daily consumption schedule without overflows outside the boundaries of the ECO. The value of the coefficient $K$ will decrease by 7% with an increase of 1000 MW of base generation in the UES of the South in the summer.

The commissioning of the Novovoronezh NPP power unit will lead to a significant shortage of the regulatory range in the UES of the South.

2.4. IES of the Middle Volga

Figure 8 shows the calculated $K$ coefficient for the winter of 2014/2015.

![Figure 8. Level of the minimum daily load of the station (without NPP) IES of the South (winter of 2014/2015).](image)

In the winter period 2014/2015, the $K$ coefficient for thermal and hydrogeneration was in the range from 65% to 78%. Thus, IES of the Middle Volga is able to cover independently the unevenness of the daily consumption schedule without overflows outside the ECO. The value of the coefficient $K$ will decrease by 4% with an increase of 1000 MW in the base generation in the Central Volga OES in winter.

Figure 9 shows the calculated coefficient $K$ data for the summer of 2014.
In the summer period of 2014, the coefficient $K$ for thermal and hydrogeneration was in the range from 57\% to 70\%. Thus, IES of the Middle Volga is able to cover independently the unevenness of the daily consumption schedule without overflows outside the ECO. The value of the coefficient $K$ will decrease by 7\% with an increase of 1000 MW of the base generation in the IPS of the Middle Volga in summer.

2.5. IES of Ural

Figure 10 shows the calculated $K$ coefficient for the winter of 2014/2015.

---

**Figure 9.** Level of the minimum daily load of the station (without NPP) IES of Volga (summer of 2014).

**Figure 10.** Level of the minimum daily load of the station (without NPP) IES of Volga (winter of 2014/2015).
In the winter period 2014/2015, the coefficient K for thermal and hydrogeneration was in the range from 84% to 90%. Thus, UES UES is able to cover the unevenness of the daily consumption schedule without flowing beyond the boundaries of the ECO. The value of the coefficient K will decrease by 1% with an increase of 1000 MW of the base generation in the UES of the Urals in the winter period.

Figure 11 shows the calculated coefficient K data for the summer of 2014.

![Figure 11. Level of the minimum daily load of the station (without NPP) IES of Volga (summer of 2014).](image)

In the summer period of 2014, the coefficient K for thermal and hydrogeneration was in the range from 84% to 90%. Thus, UES UES is able to cover the unevenness of the daily consumption schedule without flowing beyond the boundaries of the ECO. The value of the coefficient K will decrease by 1% with an increase of 1000 MW of the base generation in URES UES in the summer period.

2.6. IES of Siberia

Figure 12 shows the calculated K coefficient for the winter of 2014/2015.

![Figure 12. Level of the minimum daily load of the station (without NPP) IES of Siberia (winter of 2014/2015).](image)
In the winter period 2014/2015, the coefficient $K$ for thermal and hydrogeneration was in the range from 85% to 90%. Thus, the IPS of Siberia is able to cover independently the unevenness of the daily consumption schedule without overflows outside the boundaries of the ECO. The value of the coefficient $K$ will decrease by 1% with an increase of 1000 MW of the base generation in the IPS of Siberia in the winter period.

Figure 13 shows the calculated coefficient $K$ data for the summer of 2014.

In the summer period of 2014, the coefficient $K$ for thermal and hydrogeneration was in the range from 84% to 88%. Thus, the IPS of Siberia is able to cover independently the unevenness of the daily consumption schedule without overflows outside the boundaries of the ECO. The value of the coefficient $K$ will decrease by 1% with an increase of 1000 MW of the base generation in the UES of Siberia in the summer period.

**Figure 13.** Level of the minimum daily load of the station (without NPP) IES of Siberia (summer of 2014).

In the summer period of 2014, the coefficient $K$ for thermal and hydrogeneration was in the range from 84% to 88%. Thus, the IPS of Siberia is able to cover independently the unevenness of the daily consumption schedule without overflows outside the boundaries of the ECO. The value of the coefficient $K$ will decrease by 1% with an increase of 1000 MW of the base generation in the UES of Siberia in the summer period.

**The regulatory range and location of nuclear power plants (NPP).**

The results of the calculations showed:

- Deficiency of the regulatory range in the IPS of the North-West, IPS Center and IES of the South;
- availability of free regulation range in UES URAL and UES of Siberia.

Figure 14 presents information on regions that have a free regulatory range and the location of existing and under construction NPPs on the territory of the Russian Federation and the Republic of Belarus.
Operating and under construction NPPs (indicated by red circles) are located on the western border of the Russian Federation and in Belarus, and the regulatory range in the Urals and in Siberia is thousands of kilometers away.

To calculate the required volumes of electric power flows (export / import), the modernized formula (1) can be used.

\[
K = \frac{p_{\text{con}} \min - \sum p_{\text{bas}} \sum p_{\text{gen}} + P_{\text{exp}}}{p_{\text{con}} \max - \sum p_{\text{bas}} - P_{\text{imp}}} \tag{3}
\]

where:

- \( P_{\text{exp}} \) - Electric power flow from the power system (export)
- \( P_{\text{imp}} \) - Electric power flow into the power system (import)

Ineffective placement of generating capacities leads to significant unjustified costs for grid construction.

Conclusions:
The performed calculations showed a non-optimal location of the "base" generation in the territory of the Russian Federation.
The proposed method allows:
- determine the presence and absence of an adjustment range in the energy system as a whole or in its individual parts;
- avoid errors in the location of generating capacities in the territory of the Russian Federation, including nuclear power plants, heating plants, "green" generation;
- optimize the cost of building a network infrastructure.

References
[1] Modern market of the electric power industry of the Russian Federation. UC NP"market Council" Moscow, 2015, 395 p.
[2] Andreev A, Nowicki D., Novikov N., Mitevska N. / Some approaches to the formation of the market of system services to provide automatic secondary regulation of frequency and power flows to UES of Russia "energy" No. 7/8, 2010.
[3] "Generation and consumption (hour)". Reports of JSC "so UES" ures for June-August 2014 and December 2014 – February 2015.
[4] "Report on bidding zones the free flow of UES". Reports of JSC "ATS" for June-August 2014 and December 2014 – February 2015.