

Influence of climate data quality on predictive accuracy of production and consumption of energy resources by a city

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Abstract. The article provides a list of hazardous climatic phenomena and examples of some of their effects on the constituent structural elements of the power plant. In the framework of this article, the impact of the duration of hot weather on the operation of nuclear power plants is considered. An analysis was made and the stations most susceptible to global climate change in terms of increasing summer temperatures were identified. For the two most representative stations, modeling based on artificial neural networks was performed and conclusions were drawn about an increase in the number and duration of hot days per year. The best forecast result for St. Petersburg NPP is 54.59%, for Kursk NPP - 22.18%. The structure and method of formation of the predictive function are analyzed. Methods are proposed to improve the accuracy of the forecast by varying the discretization value of the initial data, as well as by changing the activation function of the artificial neural network.

1 Introduction

Structures and engineering filling of gas or nuclear power plants (PP) are designed with increased reliability. As a result, their construction is quite expensive. The lifetime of the plant in previous periods was assumed to be 30 years, later extensions up to 60 years began to apply. The practice of extending the service life of the station up to 100 years is currently being used. Over such periods of time, the climate changes so much that the degree of its change cannot be predicted at the design stage. Thus, many stations require additional modernization during the operational life.

Taking into account modern climatic factors becomes even more relevant with the intensification of climate change, noted in the last 15-20 years. Hazardous climatic phenomena began to be observed in regions where they had not previously occurred. The intensity of climatic phenomena uncharacteristic for all regions of the planet is increasing annually.

Even for the temperate climate of Moscow, over the past 15 years, there has been an intensification of dangerous climatic phenomena that are not taken into account when designing energy facilities:

- Extreme fire danger and heavy haze from fires, July - August 2010.

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- Strong ice-hoar frost deposits (freezing rain), December 2010.
- Very heavy snow, December 2014.
- Heat wave, January 2014 (almost the whole of January the temperature in the Moscow region did not fall below +5°C).
- Heat wave, December 2015 (for almost the entire month the temperature in the Moscow region did not fall below +3°C).
- Continuous heavy rain (flood), February 2016.
- Flurry, May 2017.

Every year the number and intensity of dangerous climatic phenomena in all regions of the planet is increasing. The lack of rain, combined with extreme heat in 2022, has caused China's Poyang Lake to become very shallow. The water level in the lake dropped to 1.27 thousand meters above sea level - this is the lowest level since the beginning of observations in 1847 [1]. In 2022, the Yangtze River experienced 80% less rainfall, forcing several nearby factories to shut down due to lack of hydropower [2]. In 2022, the landscape of Western Europe has also changed, including due to the drying up of the Rhine River in Düsseldorf, Germany, and the Loire River in France [3]. Storm 08/31/2022, registered in Catalonia became the strongest in the last 20 years [4]. Individual hailstones exceeded 10 cm in diameter. The list goes on.

Almost all dangerous climatic phenomena not only increase the consumption of electrical and thermal energy, but also, as a result, have a negative impact on the volume of energy generation by generation facilities. Sometimes they lead to noticeable accidents. Thus, an anomalous increase in temperature (over 30 °C) in May 2005, combined with equipment imperfections at the "Chagino" Moscow electrical substation, led to the disconnection of HPP No. 1 and GRES-4 from the network, as well as to the loss of synchronism and shutdown of five Moscow CHPP power plants, and 15 more feeding centers [5]. 6.5 million people in 5 regions fell into the power outage zone.

Another example of the impact of a dangerous climate event is the Texas Energy Crisis February 15-20, 2021. From February 1 to February 5, 2011, Texas was covered by a snow storm with a temperature of -19 °C. The demand for electrical energy has increased significantly due to the massive inclusion of heating appliances by the population. But 23% of Texas' generating capacity was wind farms that were shut down due to high winds. In addition, power plants using other energy carriers, such as natural gas, also failed due to icing or mechanical failures. were not adapted to work at unexpectedly low temperatures. As a result, there was a desynchronization of the power system with the subsequent disconnection of more than 25% of consumers in the state. At the peak of the blackouts, more than 5 million people in Texas were left without power [6].

Nuclear power plants are also subject to accidents. During the design process of the Fukushima nuclear power plant in the 60s of the XX century, the maximum wave height was 9 meters. For 50 years, climate change has turned out to be more intense than the calculated values. The heating of the water layers of the ocean led in 2011 to the possibility of waves up to 13-15 meters [7]. The result is flooding of the building with reactors and turbines.

Another example of the impact of significant climate change on ESs is the annual droughts in Europe. Electricite de France nuclear power plants, designed for climate conditions in 1970-1980, in the summer of 2022 were forced to reduce power at some reactors on the Rhone and Garonne rivers [8]. Similar outages due to drought and heat occurred in 2018 and 2019. A significant increase in temperature in the next decade is predicted both in some regions of Russia and in Turkey, Egypt, and India.

The intensity of the occurrence of dangerous climatic phenomena is increasing, which is an off-design regime according to the norms of 30-50 years ago. Energy consumers of cities adapt to heat waves in summer easily - by increasing electricity consumption for air

conditioning. Power plants need to generate more electrical energy and at the same time increase the release of thermal energy through cooling towers, which is not always fully possible.

2 Materials and methods

Solving the issue of substantiating a sufficient degree of discretization of climatic factors in predicting the impact of production and consumption of urban energy resources, it is necessary to identify a number of factors influencing this process. The model list includes several hazardous meteorological phenomena (HMEs) that can reduce the reliability of electrical generating station components. Group of dangerous meteorological phenomena: very strong wind, hurricane wind, squall, tornado – can lead to:

- Destruction of insulators of power lines (TL) and substations.
- Overlap of wires with subsequent disconnection of the power line.
- Insufficient capacity of the batteries required to ensure the plant's operability in the event of a disruption in the supply of electricity.
- Damage to the transmission elements of switchgears of electrical substations.

Group of dangerous meteorological phenomena: prolonged heavy rain, heavy downpour, very heavy rain, very heavy sleet, very heavy sleet, very heavy sleet and rain - may in addition to the above lead to:

- Damage to switchgears of electrical substations.
- Growth of own needs due to the increase in losses for the corona discharge of power lines.
- Flooding of the foundations of permanent and temporary structures.
- Violation of the operation of measuring and transmitting automatic control systems (ACS) of the power plant.
- Changes in the operating modes of the water intake system.
- Decrease in the efficiency of the heat transfer process and accelerated wear of heat exchangers when using water from cooling pools due to an increased rate of nitrification of water by agricultural effluents.
- Raising the water level of the cooling ponds to a level for which the station was not designed.
- If the station is located at sea, the probability of flooding due to the increased power of the storm.

Very heavy snow, heavy blizzard, heavy ice can cause:

- Frost deposits - to sticking of snow on wires with subsequent breakage.
- Snow sticking to the current-carrying parts of substations, followed by a short circuit (short circuit) and disconnection of the power line.

Large hail can cause:

- Damage to the insulators of power lines with subsequent disconnection of the power line.
- Damage to the current-carrying parts of substations with subsequent disconnection of the power line.
- Damage to the translucent structures of buildings, building structures.

A severe dust or sandstorm can cause:

- Overlap of wires with subsequent disconnection of the power line.
- Electrostatic sand build-up on the transmission elements of switchgears of electrical substations, followed by a short circuit and disconnection of the power line.

Group of dangerous meteorological phenomena: emergency fire hazard; heavy fog; strong haze; abnormally cold weather; Freezing can cause:

- Electrostatic sticking of sand (soot) on the transmission elements of switchgears of electrical substations with subsequent short circuit and disconnection of the power line.
- Reducing the efficiency of air intake and purification devices.
- Reducing the efficiency of cooling towers.
- Increasing the load on electric heating of consumers, which leads to a change in modes and a subsequent reduction in the resource of reactor elements, pumps of the primary cooling system.
 - Increasing the uneven supply of heat and electricity.

Extreme heat and abnormally hot weather can cause:

- Reducing the efficiency of transformer cooling systems.
- Decrease in the efficiency of the cooling systems of the primary circuit.
- Decrease in the efficiency of the cooling systems of the secondary circuit.
- Decrease in the efficiency of the oil cooling systems of auxiliary units.
- Decreased efficiency of the water intake system from cooling reservoirs due to their shallowing.
- Decrease in work efficiency and accelerated wear of the water purification system from cooling reservoirs due to increased vitality of biological flora.
- Increasing the need for increased water flow through the heat exchangers of the water purification system from cooling reservoirs, which may not be provided for by the design of the station.
- Transition to reduced modes of electricity generation due to insufficient operation of the system of cooling towers and cooling reservoirs.
- Growth of costs for the use of water resources due to the intensification of the growth of water tariffs.

A change in the wind rose and a change in the intensity of cloud cover can cause:

- The need to quickly change modes with a subsequent reduction in the resource of reactor elements, pumps of the primary cooling system, which occurs due to the uneven schedule for generating electricity to the grid by wind and solar stations.

Changes in the schedule and intensity of precipitation, increased seasonal droughts and rains can cause:

- Insufficiency of the existing capacity of the cooling basins.

In addition to the listed hazardous meteorological phenomena, the factors affecting the operation schedule of the power plant include the influence of renewable energy sources on the power grid modes:

- An increase in the installed capacity of RES leads to a strong distortion of the operation mode of the power plant operating in the base mode.
- The power grid may need to back up 100% of solar and wind power generation capacity.

The list goes on. Within the framework of this article, an assumption was made that only one dangerous meteorological phenomenon affects the process of production and consumption of urban energy resources - intense heat; the outside air temperature is assumed to be at least 30 °C.

Climate change is regional in nature. In different regions of the planet, various dangerous climatic phenomena will intensify, their change will have different intensity. Thus, the climatic conditions for all existing and planned nuclear power plants must be adapted to accelerating climate change.

In Russia, the observed climatic trends in the growth of the average annual temperature in Russia for 1976-2021. According to Roshydromet, they are local in nature (Figure 1). Taking into account the geographical location [11], the most subject to climate change are nuclear power plants: Kol'skaya; Bilibinskaya; Leningradskaya; Kursk.



Fig. 1. Observed climatic trends in the growth of the average annual temperature in Russia for 1976-2021 [12].

The number of hot days per year for power plants that are most susceptible to changes in outdoor air temperature are shown in Table 1.

Table 1. Intensity of change in the number of hot days in the period from 2015 to 2022 [13].

Years	NPP St. Petersburg	NPP Bilibino	Kol'skaya NPP	Kursk NPP
2015	0	3	0	11
2016	1	0	0	12
2017	0	0	0	9
2018	5	0	2	8
2019	4	2	0	9
2020	2	0	0	12
2021	19	3	0	29
2022	10	0	0	13

Based on the data obtained, it becomes obvious that the highest intensity of the increase in the number of hot days is observed for the nuclear power plants in St. Petersburg and Kursk.

3 Results

The initial data to justify a sufficient degree of discretization of climatic factors in predicting the impact of the production and consumption of energy resources by cities are data on the daily outdoor temperature. The training sample for each power plant is 2555 data lines (Figure 2): from 01/01/2015. until 31.12.2021; measuring accuracy -0.1 °C. The test sample has a similar accuracy and is 365 lines - from 01/01/2022. until 31.12.2022.

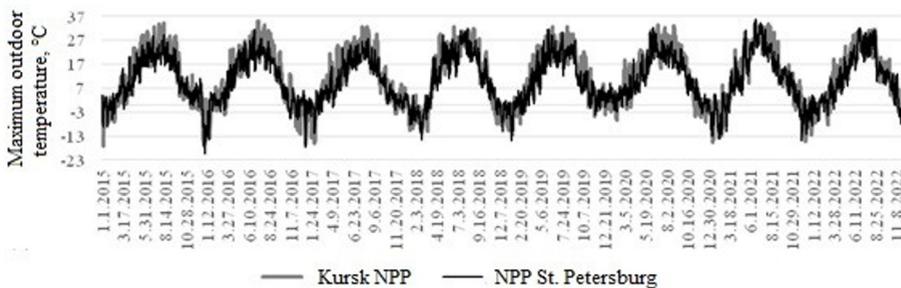


Fig. 2. Outside air temperature values from training and test samples for Kursk and St. Petersburg NPPs.

A neural network is used with the number of input layer neurons 2; number of hidden layers = 1; the activation function is a sigmoid with curvature 2. Despite the rather large sample size and its high reliability, the best forecast result for St. Petersburg NPP is 54.59%, for Kursk NPP - 22.18%.

4 Discussion

Based on the insufficiently high accuracy of the results obtained, it is not possible to implement a reliable forecast. It is acceptable to use the scenario approach. Figures 3 and 4 show forecasts of changes in the number of days with hot weather for the Kursk and St. Petersburg NPPs.

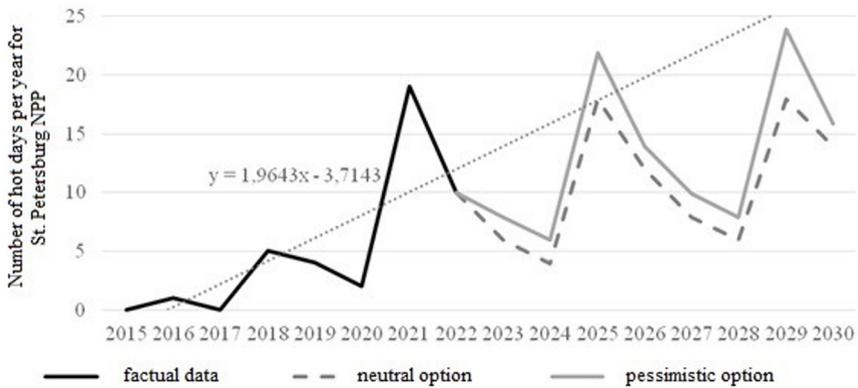


Fig. 3. Forecast of the number of hot days per year for the St. Petersburg NPP.

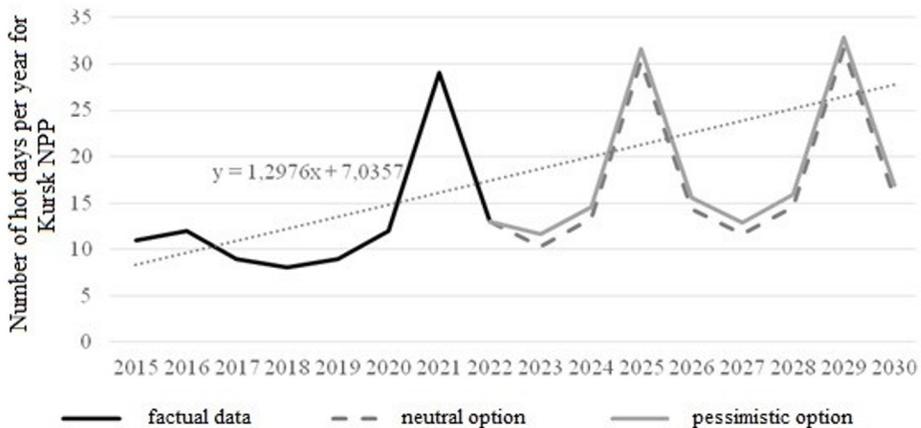


Fig. 4. Forecast of the number of hot days per year for Kursk NPP.

5 Conclusion

Based on the received data, it becomes possible to conclude that the described approach is applicable for training an artificial neural network and forming a predictive function.

The discretization of the climatic factor used with a measurement accuracy of 0.1°C is sufficient. The applied assumption about the impact on the process of production and consumption of energy resources of cities of only one dangerous meteorological phenomenon "intense heat" is necessary, but insufficient, because the forecast accuracy obtained is not high enough: for St. Petersburg NPP - 54.59%, for Kursk NPP - 22.18%.

The applied configuration of the artificial neural network is satisfactory. At the same time, the activation function used, apparently, is not optimal in terms of the achieved accuracy - a sigmoid with a curvature of 2. With an increase in both the duration of the hot summer period, and with an increase in air temperature and, accordingly, limiting the ability of nuclear power plants to produce electricity. This character corresponds to a sigmoidal activation function with a curvature greater than 3.

The resulting scenarios for an increase in the number of hot days per year for the city of Kursk and St. Petersburg clearly demonstrate an increase in the intensity of the analyzed indicators. Even under the conditions of the obtained satisfactory accuracy of the forecast, it can be concluded that the St. Petersburg NPP is most susceptible to climate change. It is advisable to improve the accuracy of the predictive function taking into account a more detailed multivariate analysis of climate change. The topic of separate groups of studies is the detailed correlation of each dangerous meteorological phenomenon and the most effectively describing its type and parameters of the activation function.

Acknowledgement

The investigation has been carried out within the framework of the project "Development of neural network software for forecasting the demand for thermal energy by objects of mass construction in the city of Moscow with the support of a subvention from the National Research University "MPEI" for implementation of the internal research program "Priority 2030: Future Technologies" in 2022-2024.

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