Impact of the climate change on the performance of the steam and gas turbines in Russia

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Abstract. The power generating industry is known to be vulnerable to the climate change due to the deteriorating efficiency of the power equipment. Effects for Russia are not completely understood yet. But they are already detected and will be more pronounced during the entire current century, as the Russian territory is one of the areas around the world where the climate change is developing most rapidly. An original climate model was applied to simulate the change of the air temperature across Russia for the twenty-first century. The results of the climate simulations were used to conduct impact analysis for the steam and gas turbine performance taking into account seasonal and spatial heterogeneity of the climate change across the Russian territory. Sensitivity of the turbines to the climatic conditions was simulated using both results of fundamental heat transfer research and empirical performance curves for the units being in operation nowadays. The integral effect of the climate change on the power generating industry was estimated. Some possible challenges and opportunities resulted from the climate change were identified.

1. Motivation

The climate change is probably the most discussed problem nowadays. Mechanisms and reasons of the climate change aren’t quite clear yet with all detail. However, undeniable shift of the climate conditions has been observed during last decades. Impacts of that change in still evident. These processes are very likely to continue during the next century even considering moderate scenarios. Research efforts and political negotiations are indented to work out adaptation and mitigation measures considering all regions of the world and taking into account all aspects of humans’ life.

The energy systems are impacted by the climate change in a number of ways. One of the most vulnerable types of electricity generation is known to be thermal generation, e.g. due to needs on cooling media, an efficiency decrease of the thermodynamically processes, increasing risks for infrastructure and so on. Such effects were studied in details for energy systems of US and European Union and have identified some considerable penalties linked to the climate change [1]-[7].

Systematic analysis of climate-associated risks for Russian power systems wasn’t done yet. An Assessment report of the Russian Meteorology agency Roshydromet [8] has denoted an assessment of the climate change impacts on the power industry as one of research gaps. However, the studies of some particular aspects only has appeared since then [9]-[11].

Susceptibility of the thermal power plants to the climate warming may imply significant risks for Russian energy systems as thermal power generates about 60-70% of electricity in Russia (fig. 1). Such structure of the energy industry is combined with exceptionally high warming rates on Russian territories.
Figure 1. Electricity generation in Russia by types of technology used

Our work is aimed to fill an existing research gap and give the first systematic picture of the climate change impacts on Russian power generation. We were intended to use robust, physically-based approaches to be as independent as possible on changing economic conditions and organizational structure of the power industry. The work scope was restricted by thermal and nuclear power plants contributing to more than 80% of the electricity generated.

2. Simulation approaches
The main idea of the research was to couple regional projections of the climate change in Russia with simulation of physical processes which are responsible for climate sensitivity of the power plants. Parameters of the plants were taken as close as possible to the parameters of the units being in operation in the Russian power system considering some progress during next decades. Deterioration of the plants’ performance due to the climate warming was the main subject of the study. Besides, we have used the established approaches to identify some risks associated with the climate change for Russian power industry and to define directions of further work.

2.1. Assessment of the climate change
An original climate model established in the Global Energy Problems Laboratory (GEPL) was used to construct projections of seasonal and annual temperatures across Russian regions. The models combines simulation of global-scale mass and energy transfer processes with statistical assessment of contribution of main climate drivers to regional manifestation of the global climate processes. Good correspondence of the GEPL model to observational data was demonstrated in a variety of regional studies during last 25 years [12]-[13].

2.2. Simulation of the power equipment
Steam and gas turbines were chosen for simulation as the main types of thermal engines being in operation. Simulation of the steam turbines was based on representation of thermodynamic and heat transfer processes which define sensitivity of the turbines output to the change of ambient temperature. Particularly, the processes in condenser were modeled quite in details considering a spread of design
and operational conditions [14]. Performance of the gas turbine was represented by an operational curve of a real unit. The unit’s type was chosen to correspond approximately to a fleet-averaged parameters [14].

The response curves assumed for further impact analysis are presented in the fig. 2. It should be noted that nuclear power plants demonstrate most pronounced performance deterioration due to the climate warming. The response curve of the steam turbine was additionally modified to take into account linking of the cooling water temperature to the ambient air one using empirical evidence and simplified theoretical model [15].

2.3. Impact study
Regionally statistics was used to represent installed capacity of steam and gas turbines by Russian regions. Resolution of such representation was defined by peculiarities of statistic data. Operation of steam turbines was considered on larger areas corresponding to subsystems of the Russian power systems. Gas turbines have required more detailed representation due to their concentration in some certain Russian regions. Inertial scenario have been assumed for technical parameters both the power system and power equipment. Base period was defined as 1961-2010, the year 2050 was taken as a time horizon for the study.

3. Results
Decrease of the power output was found to be about 0.2% and 0.5% per 1°C of ambient air warming for the steam turbines of the thermal and the nuclear plants respectively. Corresponding increase of fuel consumption increase will be about 0.15-0.45% and 0.3-0.8%. The most pronounced effect will be observed in Ural region and in Siberia due to high warming rates.
Figure 3. Increase of the fuel consumption $B$ of the steam turbines working on the thermal power plants and the power drop $N_{el}$ of the turbines associated with 1°C warming.

Figure 4. Increase of the fuel consumption $B$ corresponding to the performance deterioration of the steam turbines working on the nuclear power plants and the power drop $N_{el}$ of the turbines associated with 1°C warming.
Increase of the fuel consumption by the gas turbines will be of order 0.2-0.3% for all regions except Far East where moderate rates of the climate change are combined with low temperatures linked with low turbines’ sensitivity to the ambient air warming.

![Figure 5. Increase of the fuel consumption B of the gas turbines and the efficiency drop $\Delta n$ of the turbines associated with 1°C warming](image)

4. Discussion and recommendations
An integral impact of the climate warming may be estimated as approximately 3-4 millions tons of coal equivalent (tce) additionally spent each year by the power industry to compensate the performance deterioration of the thermal and nuclear plants. That corresponds by a value order to a power output of a single nuclear power plant. But it’s of two orders lower compared with characteristic constants of the Russian energy system. The first one is the fuel saving due to reduction of the space heating demand resulted from the climate warming which is estimated as about 100 millions tce yearly [16]. The second one is potential of efficiency increase of the Russian energy system being as high as 100-200 millions tce per year.

An overall effect of the climate warming on the Russian energy sector was found to be clearly positive. However, even such a robust analysis has identified some threads connected with a shift of the operation regimes of the power equipment. The steam and the gas turbines has be found to give qualitatively different response on the same change of the ambient air temperature. That mean potential problems for the combined-cycle units being currently a mainstream of development of the Russian power industry. This issue requires a more careful research analysis which should be a subject of future work.

Acknowledgments
This work was supported by the following organizations: the Russian Foundation for Basic Research in part of simulation of climate impacts on the performance of power equipment (project no. 15-08-01225); the Russian Science Foundation in part of analysis of regional energy systems (project no. 16-19-10568). The authors acknowledge as well the Ministry of Education and Science of the Russian Federation for supporting V.V. Klimenko (grant 13.4662.2017) and E.V. Fedotova (Kasilova) (a grant for young scientists MK-1494.2017.8).
References

[1] Stanton MCB, Dessai S and Paavola J 2016 *Energy* **109** 1148–59.
[2] Vliet MTHV, Wiberg D, Leduc S and Riahi K 2016 *Nature Climate Change* **6** 375–80
[3] Jaglom WS, Mcfarland JR, Colley MF, Mack CB, Venkatesh B, Miller RL, et al 2014 *Energy Policy* **73** 524–39
[4] Bartos MD and Chester MV 2015 *Nature Climate Change* **5** 748–52
[5] Cook MA, King CW, Davidson FT and Webber ME 2015 *Energy Reports* **1** 193–203
[6] Ke X, Wu D, Rice J, Kintner-Meyer M and Lu N 2016 *Applied Energy* **183** 504–12
[7] Hoffmann B, Häfele S and Karl U 2013 *Energy* **49** 193–203
[8] Roshydromet's Second Assessment Rep. on Climatic Changes and Their Consequences on the Territory of Russian Fed. 2014 Ed VM. Kattsov and SM Semenov (Moscow: Rosgidromet,, 2014) [in Russian]
[9] Shkolnik IM, Meleshko VP, Stadnik VV, Khlebnikova, EI, Akent'eva EM, Genikhovich EL and Kiselev AA 2014 *Proc. of Voeikov Main Geophysical Observ*. **573** 92-222 [in Russian].
[10] Akent'eva EM, Sidorenko GI and Tyusov GA. 2014 *Proc. of Voeikov Main Geophysical Observ*. **570** 95-105 [in Russian].
[11] Klimenko VV, Klimenko AV, Kasilova EV, Rekunenko ES and Tereshin AG 2016 *Thermal Engineering* **63** 690–8
[12] Klimenko VV, Klimenko AV, Tereshin AG and Mikishina OV 2002 *Izv. Akad. nauk.Energetika* No. 2 10-27 [in Russian].
[13] Klimenko VV, Tereshin AG , Beznosova DS et al. 2004 *Izv. Akad. nauk.Energetika* No. 4 135-145[in Russian].
[14] Kasilova EV, Klimenko VV, Tereshin AG 2017 *Proc. of 14th Intern. Conf. of young scietists on energy issues (Kaunas)* 170-179
[15] Mohseni O and Stefan H 1999 *J. of Hydrology* **218** 128–41
[16] Klimenko VV, Klimenko AV, Tereshin AG et al. Changing pattern and amount of the residential and commercial energy consumption in response to economic and climatic factors. 2012 *Thermal Engineering* **59** No. 11 p. 807-815.