Influence of Temperature Drop on Power and Gas Systems - analysis

Niko Mandić [#1], Hrvoje Glavaš [*2], Ivica Petrović [#3]

[1#] *HOPS Zagreb*
Kupska 4, 10000 Zagreb, Croatia
[1] nmandic@hops.hr

[2*] *Faculty of Electrical Engineering, Josip Juraj Strossmayer University of Osijek*
Kneza Trpimira 2b, 31000 Osijek, Croatia
[2] hrvoje.glavas@etfos.hr

[3#] *HOPS Osijek*
Šetalište kardinala F. Šepera 1a, 31000 Osijek, Croatia
[3] ivica.petrovic@hops.hr

***Abstract* - Electric and gas systems are two complementary, interconnected energy systems. Each of the systems has a different size and coverage. Their networks cover different areas, the structure of their customers varies across regions, and their presence varies in industry and households. The interrelatedness of these systems is both direct and indirect. The direct interrelatedness is visible in the tasks performed by the gas system in its function of a supplier for electricity production plants. Other than the mentioned direct connection, tasks performed by these two systems complement each other while supplying the consumers, for instance in tasks of heating, hot water preparation, and similar. However, there are also some specific features that create an impression that some systems' elements are separated. The indirect connection regards climate conditions. The aim of the paper is to analyse and present the impact which a temperature drop has on electric and gas system, as well as to analyse the interrelatedness of the two systems in extreme weather conditions taking Zagreb, Croatia as an example area. In winter the consumption of electrical energy and gas rises considerably. Any shortage leads to reactions. A threat to one system indirectly endangers the other. The paper tries to clearly present the systems' very important interrelatedness and interdependence in terms of higher demand for energy-generating products using the example of temperature drop. An immediate and considerable temperature drop provokes very similar responses from both systems. This phenomenon has not been recognized clearly enough by the professional community, and its consequences have not been fully considered.**

Keywords: energy, power system, gas system, temperature drop

I. INTRODUCTION

Air temperature is a variable which changes cyclically and has a direct impact on the consumption of energy-generating products throughout the year as well as on the operation of power systems (EES). A drop in temperature leads to an increase in the consumption of energy-generating products. The increase in consumption consequently leads the system to more complex conditions of operation.

Households make up a significant portion of electrical energy and gas consumption in the Republic of Croatia (RC). This sector strongly influences the stability of power system and gas system [1]-[4]. In winter the consumption of energy-generating products is generally higher than in summer, therefore the operation of both systems is more complex. A short-term drop in temperature during a cold, winter period increases consumption notably at puts additional strain on the system. An example of such short-term drop in temperature which occurred on 24 January 2006 is analyzed and represented in the following text. The effect on power system was presented first, than the effect on smaller gas system. The effect of this temperature drop is based on the comparison of loads in power systems during the fourth (CW_4 - Calendar Week) and the third week (CW_3) of the year 2006.

The aim of this work is to present the reaction of the power system and gas system to a short-term deviation of temperature from predicted values which were the basis for planning system management. Operation planning in power system and gas system is an elaborate process which is conducted on short-term and long-term level. One of the tasks as well as the basic challenge in the writing of this paper was gathering relevant data which illustrate responses to a short-term drop in temperature. The responses of the systems are recognised in the load (consumption) increase. The higher consumption is caused by consumers, this is their answer to the temperature drop. It was noticed that in this specific example of a temperature drop, none of the systems went through a significant disturbance which would have unforeseeable consequences, such as a partial or complete blackout, even with exceptionally high additional load and strained operation of the system. [5]

The Croatian power and gas system are interconnected, complementary systems, and their mutual influence is especially conspicuous during a colder period of the year. This is the reason why a disturbance in one system is transferred to the other. Throughout the year, the system operation can be modelled and analyzed. Under special circumstances, the system's reactions become much more complex, and modelling such status and operation is unpredictable and unreliable. The identified difficulties in planning special circumstances have determined the appearance of graphs of the impact of the temperature drop on the power systems.

Here these are the graphs of mutual interrelatedness W=(*f*)t. Several types of illustrations are presented below.

An effect of a particular cold spell cannot be considered in only one of its aspects. Every day of the week is special in terms of consumption and it is characterised by a specific weighting factor. This is why the day of the week is indicated next to each date in graphs. Empirical data shows that the maximum load occurs in the middle of the week, if all other factors are weak.

Another peculiarity of the Croatian power system is its form. The Croatian power system has a peculiar arch-like form with two arms. One arm stretches from Zagreb region to Osijek, the other from Zagreb region across Rijeka to Dubrovnik. It covers the continental and costal areas of the country. Also from the point of view of climate, the Republic of Croatia can be divided into a continental and costal area. The reference data on temperatures for the continental part were measured in Karlovac and for the coastal area the data from Šibenik were used [7]. The regions of Zagreb and Osijek account for the most significant portion of energy consumption, as well as Rijeka and Split at the coast. Each region provides a different response. Due to its accessibility, natural gas is frequently used for space heating in the continental area. In the coastal region, the most frequently used energy-generating product is electrical energy. A borderline cannot be drawn between the responses to a temperature drop by these two parts of the same system. The response of the entire Croatian power system in winter days is a sum of impacts of the two regions.

II. Power systems review

Climate changes which we refer to as cold spells in general have various intensity and duration, and their influence on power systems is unrepeatable. Here we are considering an example of a change in winter temperature based on available data on electrical energy consumption in the Croatian power system and on natural gas consumption of wider area surrounding Zagreb at an hourly level. System comparison is a methodologically complex procedure and in our case a difficult challenge. The data are uneven or partially accessible. In our case the basic difficulty lay in finding two units within the same region to be compared since the coastal area of RC does not have a developed gas distribution network. In addition, after 2006 it is difficult to find a suitable example of a temperature drop during winter in which the consumption could not have been affected by the economic crisis. The economic crisis and a change in the price of energy-generating products have altered the consumption of these products [6]-[9]. Renewable energy sources also significantly contributed to the modifications in structure of electrical energy production. With their uncertain production, these sources introduced a number of changes in the system operation. The temperature drop in question occurred in the fourth week of the year 2006. This was the initial event which prompted analysis. The fact that power system covers the entire RC and that there is a unique data base referring to it, resulted in the choice to analyse electrical energy consumption in the Croatian power system in the fourth week of 2006.

A. Impact of temperature drop on Croatian power system

The representation on the influence which the temperature drop had on power system is based on two types of graphical illustrations. The first type is a representation of hourly load changes, while the second is based on comparison of daily energy consumption during two consecutive weeks. The best way to learn about the impact of temperature is to take the example of two weeks, CW_3 from 16 to 22 January and CW_4 from 23 to 29 January 2006. Daily consumption and the difference in consumptions were determined for every day of these two weeks. Hourly temperatures in the third week were more or less equal to the expected temperatures during winter and they are marked with t_1. This is the upper temperature curve in the figure 1. During the fourth week there was an intense shot-term breach of cold air mass on Tuesday afternoon. A series of hourly temperatures during this week are marked with t_2. The curve made by these temperatures is set lower than the curve marked with t_1. During the period with lower hourly temperatures, which are marked with t_2, there was a higher energy consumption. The shaded area between the curves of hourly temperatures illustrates the difference in temperatures Δt between the two weeks. The increase in electrical energy consumption cause by the temperature drop is visible as the surface between hourly loads of the two weeks ΔW. The increase varies in value during all the compared days. [9]

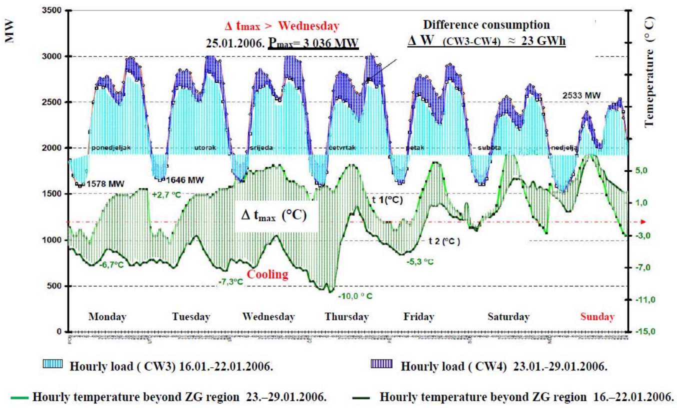

Fig. 1. Comparison of hourly consumption of electrical energy in the RC during two consecutive weeks (CW_3) and (CW_4) in January 2006 [1]-[4]

In the period from 8 to 22 every day of the fourth week, hourly consumption grew by 8% to 15% in comparison to the previous week. However the biggest growth within a day occurred during peak hours. These are intervals in which the power system is exposed to the highest loads, so every increase in load puts additional strain on the system, resulting in a critical state. On Wednesday and Thursday of the fourth week in the period of the highest electrical energy consumption, the realized load exceeds 3 000 MW.

The maximum daily difference in loads within the Croatian power system amounted to ΔW_e= 5 681 MWh and it was registered on Wednesday, 25 January 2006.

The difference in hourly temperatures varied throughout the week. It reached the highest value on Wednesday then in shrank towards the end of the week. In total 23 GWh more were spent during the fourth week in the Croatian power system in comparison to the previous week. A short-term breach of cold air mass contributed the most to the increase in electrical energy consumption. The stated amount of energy is equivalent to a third of the daily consumption of Croatia during winter or to the total production of the nuclear power plant Krško within approximately 32 hours.

The difference in daily electrical energy consumption for the two compared weeks is shown in the figure 2. More precisely, the figure illustrates the daily values of the difference in consumptions for the Croatian power system. The differences in consumptions are marked with ΔW on the y axes and with the corresponding index (W_{CW4}-W_{CW3}) for every day of the week.

There were several ways of meeting the increased demand for electrical energy in a short period. One of the possibilities was to increase the domestic electrical energy production which could not be done in this specific case. The following possibility was to increase short-term daily import of electrical energy. In a relatively cold, dry period such as January 2006 was, there was not a significant amount of electrical energy available on the spot market. This is the reason why it was difficult to import electrical energy. Based on empirical knowledge on changes in electrical energy consumption caused by short-term temperature drop accompanied by bora winds in Dalmatia, it is our opinion that the operation of heaters and air-conditioning devices which are used for space heating greatly contributed to the increase in consumption. We consider their influence as predominant in terms of increase in electrical energy consumption in the Croatian power system during the fourth week in 2006.

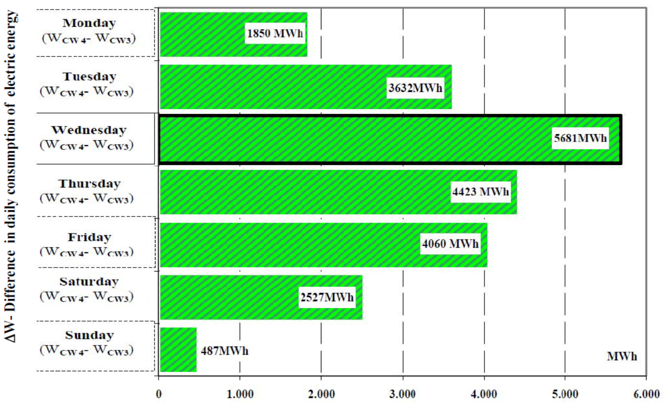

Fig. 2. Difference in daily consumption of electrical energy for the RC for two consecutive weeks (CW 3) and (CW 4) in January 2006. [4]

B. The impact of short-term temperature drop on gas system

A comparison between electric power system and gas system was feasible only within the region surrounding Zagreb and the one surrounding Osijek. Zagreb gas network is larger than the one of Osijek and due to its size, coverage and availability of data it was chosen for comparison. The figure 3 provides the best insight into the load in the gas system and its interrelatedness with temperature in 2005 and the period in question in 2006. Particularly conspicuous are the cyclical changes in consumption following the changing of seasons. In winter the consumption is noticeably higher than in summer. The ratio between winter and summer gas consumption for the wider area of Zagreb according to the data provided by Zagreb City Gassworks (Gradska plinara Zagreb GPZ) is approximately 10:1. Therefore gas consumption of this region during winter is ten times higher than summer gas consumption. A cold period during the year is also the period of the highest loads in power systems.

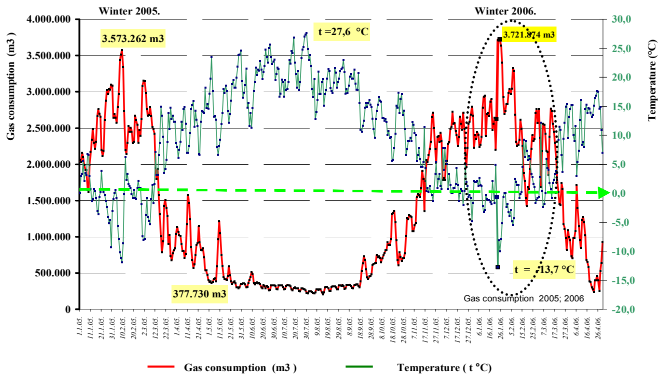

Fig. 3. Changes in daily consumption of natural gas (GPZ) as related to temperature for 2005 and 2006. [6], [8]

TABLE I

INCREASE IN GAS CONSUMPTION DURING (CW_4- FROM MONDAY 22 TO SUNDAY 29 JANUARY) IN COMPARISON WITH (CW_3- FROM MONDAY 16 TO SUNDAY 23 JANUARY) IN 2006 [6]

2006.	Week (CW_3) m^3	Week (CW_4)-(m^3) Cooling	Δ_1 (m^3)	Δ_2 (%)	CW_3->t^*_1 (°C)	CW_4->t^*_2 (°C) Cooling	$\Delta=(t^*_2-t^*_1)$ (°C)
Mo	2.834.304	3.576.304	742.000	26,18	-1,86	-9,61	-7,75
Tu	2.959.520	3.716.180	756.660	25,57	-3,43	-8,57	-5,14
We	**2.511.488**	**3.725.986**	**1.214.498**	**48,36**	**2,53**	**-10,2**	**-12,72**
Tu	**2.506.638**	**3.678.814**	**1.172.176**	**46,76**	**0,96**	**-8,96**	**-9,88**
Fr	2.676.520	3.499.310	822.790	30,74	-1,98	-6,29	-4,32
Sa	2.286.672	3.056.878	770.206	33,68	3,13	-2,44	-5,56
Su	2.358.174	2.707.580	349.406	14,82	1,1	-0,44	-1,55

The mean daily temperature t^*_1;t^*_2; (CW_3;CW_4)

The data on changes in gas load in the table 1 are sorted by days. The highest differences in gas consumption and the highest differences in daily temperatures stand out from the series of values. The difference in daily gas consumption is marked with Δ_1 and expressed in m^3 and difference in consumption expressed as percentage is marked with Δ_2.

In general the highest gas consumption was achieved following the sharp fall in temperature on 23 January 2006. During Wednesday and Thursday, the consumption increase hit the record high amounting to 48.36%, and 46.76% respectively if compared to the previous week.

The figure 4 contains the detailed representation of gas consumption increase at hourly level for the wider Zagreb area. The surfaces in the figure which illustrate the difference in temperature and in system load during the two weeks are particularly noticeable. These surfaces are coloured in green and blue. The figures 1 and 4 illustrate the impact of the temperature drop on two different systems. Air temperatures at the beginning of the fourth week showed a slight downward trend. As the week was passing by there was a sudden temperature drop. The hourly temperatures of Zagreb area which are used in the graph (Fig.4) came close to -10° C when the week started. In the middle of the week the temperatures dropped to - 13° C. The position of the curve which combines the load ΔW and the temperature variations Δt is visually somewhat different if compared to the similar illustration of the impact on the power system. A slight difference in positions of the surfaces which are highlighted in green in the figures 1 and 4, points to a difference in climates which are illustrated in these two figures. However we can say that both graphs depict very similar responses if we disregard the difference in intensity. The table 1 offers a numerical overview of the changes in gas consumption and temperature.

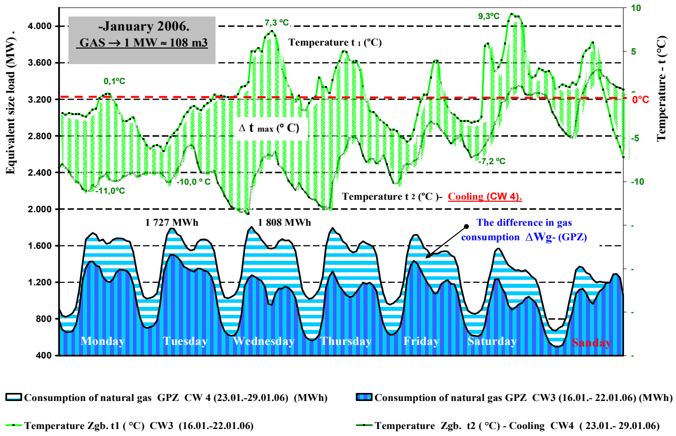

Fig. 4. Comparison of hourly consumption of gas of Zagreb City Gassworks for two consecutive weeks (CW $_3$) and (CW $_4$) in January 2006 as related to hourly temperatures [4], [5], [13]

III. Differences and Similarities in Responses of Power Systems to Short-Term Drop in Temperature

The responses of the overall electric power system and smaller gas subsystem to a short-term breach of cold air mass are similar but still different. In both systems the temperature drop leads to an increase in loads, that is, in energy-generating products. The basic difference of these systems is in their size. [7],[8] If we compare the figures 1 and 4 we see that the maximum load of the gas subsystem during the entire fourth week is equal to a half of the maximum load of the overall electric power system. The electric system covers the entire territory of Croatia and it is under various climate influences. The responses of this system bear the characteristics of coastal and continental part of the system which intertwine. On the contrary, the gas subsystem bears exclusively the characteristics of the continental part of the country. The continental temperatures are usually somewhat lower than the coastal temperatures. Therefore, due to functional interrelatedness with different areas, the curves of the temperature variations shown in the figures 1 and 4 vary considerably in value.

Furthermore, the gas subsystem located in the wider area of Zagreb covers a smaller area. If we attempt to partially compare the overall electric power systems and the smaller gas subsystem, we will reach the following conclusions. Daily responses in the gas subsystem are stronger and more dynamic than the responses of the overall electric power system. The highest increase in hourly consumption in both systems occurred during daily peak load, while increases in consumption were significantly lower during the night. The weekly increase in gas consumption during the period surrounding the temperature drop is higher than the increase in electrical energy consumption in the overall power system. [11]

There are many causes of a stronger response of the gas subsystem than the overall electric power system. The starting point of this conduct is the greater presence of gas in space heating than electrical energy. In line with the consumer model in the wider area of Zagreb, where gas is most frequently used for space heating, every significant drop in temperature results in gas consumption increase in the gas subsystem. These responses of the gas system reoccur in majority of temperature drops during January.

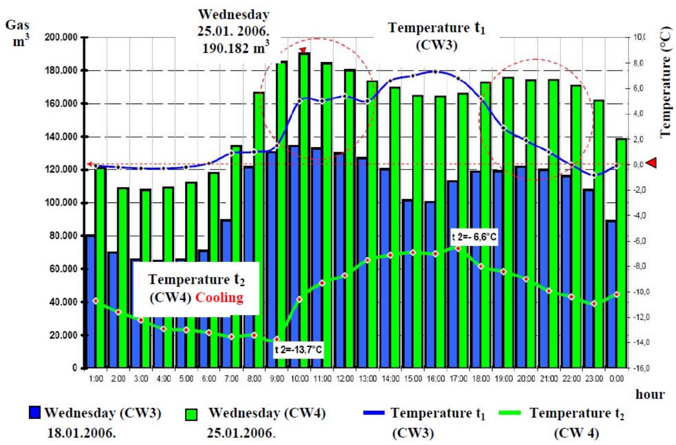

Fig. 5. Hourly gas consumption and temperatures for two Wednesdays in the weeks CW_3 and CW_4 [4], [5]

Experience in the operation of both power systems shows that power consumption in at its highest in the midweek. In the example of a short-term temperature drop on 24 January 2006, the highest power consumption was achieved in the middle of the fourth week, on Wednesday and Thursday. An already increased consumption was here further prompted by the temperature drop. Wednesday was a special day in terms of daily electrical energy and gas consumption since the gas consumption higher than usual the entire day, but also since the difference in consumption was at its highest. The figure 5 highlights several dissimilarities between the compared consecutive Wednesdays. The most significant increase in hourly gas consumption occurred during peak (a circled detail in the figure).Following the fall in morning temperatures to t_2 = -13.7°C, gas consumption suffers a further increase, so in this period there were also intense responses in the gas subsystem. The temperature marked with t_2 in the graph represents hourly value unlike the temperature marked t^*_2 which is a mean value taken as a reference data for the entire day.

IV. COMPARISON OF LOAD INCREASE IN SUBSYSTEMS OF THE WIDER AREA OF ZAGREB

A challenge of comparing electric power and gas subsystem in Zagreb area for a particular period was aggravated by a frequent change in topology of the power grid and malfunctions in some supply routes which are followed by a shut down of the power grid and remedies. A change in topology during the fourteen days in question additionally hindered a quality comparison of data on hourly electrical energy consumption. Generally speaking, during a winter period, especially a particularly cold one, there is an increased incidence of malfunctions and the topology of the local electric power system changes frequently. There are various causes: the cold, snow, ice, higher electrical load and mechanic malfunctions, which can become major disturbances and partial or complete blackout of the electric power system.

The accessible data refer to daily loads, and they are compared in the figure 6, which represents interrelatedness of variables on two y axes. On the left y axes there is a difference in system loads during two weeks, and on the right axes the corresponding difference in mean daily temperatures of the region of Zagreb. The responses of both systems are measured in MWh. The data on temperature during the third and fourth week were gathered in the four points of the wider area of Zagreb. The highest difference in temperature occurred on Wednesday and amounted to Δ (t_2*-t_1*) = 12.7 °C. It is noticeable that the increase in gas consumption during the fourth week amounted to ΔWg ~ 55.3 GWh, and the increase in electrical energy consumption to ΔWe ~ 5.5 GWh.

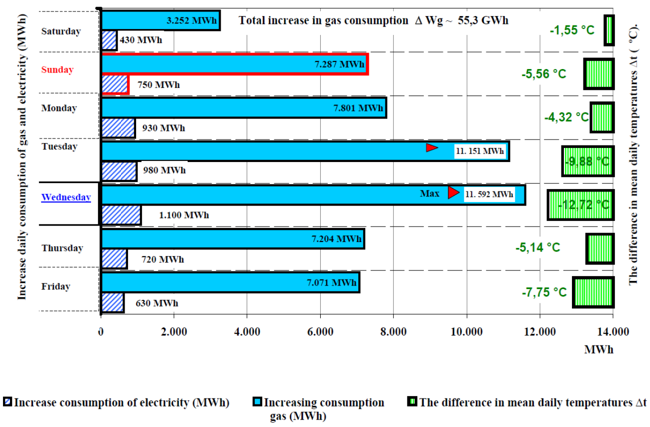

Fig. 6. Increase in total daily consumption of electrical energy (Elektra-ZG) and natural gas (GPZ) for wider area of Zagreb during the week (CW_4) in January 2006 [4], [5], 12]-[14]

In the past period, the Croatian gas and electric power systems were expanded and upgraded. Similar occurrences of a short-term temperature drop lead to mostly similar responses in the power systems, despite the fact that several new possibilities occurred for procurement of energy-generating products.

V. CONCLUSION

While determining the power systems' response to an extreme operating condition, the authors have encountered serious difficulties on several occasions. The basic issue were the data, that is, their consistency and reliability. However, after overcoming various difficulties the comparison of systems was achieved.

The comparison of power systems is a methodologically complex and very demanding task. In winter almost all productive facilities operate at peak load of their production capacity, hence the production cannot be significantly increased. The residential sector increases consumption with the aim of maintaining indoor temperature as the temperature outside drops. The analysis of the impact a short-term temperature drop on the two power systems in the third and fourth week on 2006 has been conducted, even though the systems are of different sizes, by partially comparing certain system responses.

The representation of the impact which a temperature drop had on the entire Croatian power system indicates that hourly electrical energy consumption has increased by 8% to 15%, and the highest consumption expressed as hourly load has exceeded 3 000 MW. The maximum daily difference in consumption on Wednesday 25 January 2006 in the Croatian power system amounted to 5 681 MWh, while the weekly consumption was by 23 GWh higher than in the previous week.

Based on the comparison of smaller electric power system and gas system which are located in the wider Zagreb area we can draw a conclusion: the ratio between winter and summer gas consumption is approximately 10:1. In face of the temperature drop, the gas consumption increased by 48.36% at maximum on daily level at a difference in temperature of 12.7°C. The overall weekly increase in electrical energy consumption amounted to 5.5 GWh, and the increase in gas amounted to 55.3 GWh.

The authors' experience shows that greater disturbances in the operation of electric power system lead to difficulties in the gas system. By short-term planning it is necessary to ensure sufficient amount of both gas and electrical energy, while taking into account possible disturbances in one system or the other. Through long-term and strategic planning it is necessary to have further insight into the mutual influence of the systems and consider expanding the existing gas infrastructure, that is, constructing gas-fired production facilities with verification of long-term economic justification of such plans. The analyzed examples of particular conditions in terms of a short-term breach of cold air mass and the consequential increase in consumption can contribute to the consideration of overall needs of both power systems.

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