Possible Consequences for the European Energy Sector from Violations of Russian Gas Transit Through Ukraine

Sergey Senderov, Sergey Vorobev,
Victor Rabchuk
Energy Security Department
Energy Systems Institute, ESI SB RAS
Irkutsk, Russia
ssm@isem.sei.irk.ru

***Abstract*— Events of spring 2014 have greatly escalated questions of reliability of transporting of Russian gas to European countries. Possible reduction of supplying creates problems of fuel-supply of these countries at the time of short supply of Russian gas. The article considers the essence of these problems. Particular attention is paid to reducing the supply of primary energy and fuel oil to consumers and reduces electricity production in countries - importers of Russian gas during its short supply.**

***Index Terms*-- Russian natural gas, short supply, gas consumption, primary energy.**

I. INTRODUCTION

Today Russia sells gas to greater part of European countries. The article deals with Austria, Bulgaria, Hungary, Germany, Greece, Italy, the Netherlands, Romania, Slovakia, Turkey, France and the Czech Republic. These are the countries with the largest share of Russian gas import. Gas supplies are carried out through following gas transport corridors:

- "Nord Stream" - a route of Russian gas exports to Europe, the target markets for the sup-ply are Germany, UK, Netherlands, France, Denmark and other countries;
- Pipeline "Yamal–Europe" runs across four countries - Russia, Belarus, Poland and Germany;
- Gas transport corridor "Urengoy–Uzhgorod" to enter gas to the European countries through Ukraine, Moldova, Romania and Bulgaria;
- Gas pipeline "Blue Stream" created for Russian gas supplies to Turkey under the Black Sea.

At the present time, it is possible that will be interrupted Russian gas export to Europe through corridor passing through the territory of Ukraine. Such situation have been modeled and analyzed. Particular attention is paid to reducing supply of primary energy and fuel oil and reduces electricity production during short supply of Russian gas. The following general procedure of evaluating levels of reduce the supply primary energy and fuel oil and reducing power generation while reducing the total Russian gas exports to all European countries in a given scale was adopted:

- determining the structure of consumption of primary energy and fuel oil before violation of export supplies of Russian gas, with the determining of proportion of Russian gas participating in gas consumption of the country;
- definition of the role of Russian gas in power generation and release the share of electric-ity in the whole country obtained through using the Russian gas;
- obtaining the calculated values of deficit gas for each country due to the reduction of gas exports from Russia;
- determining of quantitative indicators of supply reduction of primary energy and fuel oil and reducing the level of electricity generation for the country, in the case of short supply of Russian gas.

II. STRUCTURE OF PRIMARY ENERGY AND FUEL OIL CONSUMPTION

In the article was considered appropriate to review the conditions of functioning of systems of fuel supply of countries - importers of Russian gas for 2012. This is the year, for which there is complete required statistical information. Export supplies of Russian gas in 2012 amounted to 187 billion cubic meters of gas, while total consumption in Russia was 416 billion cubic meters of gas. The events of spring 2014 have greatly escalated questions of reliability of transporting of Russian gas to European countries. Table I shows the structure of consumption of primary energy and fuel oil for each European country, and Table II shows the

share of Russian gas in the total gas consumption of the country and share the same gas in the total volume of consumed primary energy and fuel oil. In Tables I and II for the information base used data from BP [1] and EIA [2].

Role of Russian gas in the energy sector of a country is determined by its share in the total consumption of primary energy and fuel oil (Table II). Among the considered countries the role of the Russian gas is highest in Hungary (33.4%), Slovakia (36.3%) and Austria (33.8%). This role is less noticeable in the Netherlands (3.8%), France (10.3%) and Greece (9.4%).

TABLE I. CONSUMPTION OF PRIMARY ENERGY AND FUEL OIL FOR CONSIDERED COUNTRIES IN 2012

Country	Natural gas		Coal		Fuel Oil		Total	
	Mtoe	%	Mtoe	%	Mtoe	%	Mtoe	%
Austria	10,4	64,7	2,8	17,8	2,7	17,5	15,9	100
Bulgaria	3,1	22,4	9,9	71,8	0,8	5,8	13,8	100
Hungary	11,2	67,5	4,3	25,8	1,1	6,7	16,5	100
Germany	86,5	39,4	112,5	51,2	20,8	9,5	219,7	100
Greece	4,8	17,2	17,0	60,7	6,2	22,1	28,1	100
Italy	79,0	67,1	23,0	19,5	15,7	13,3	117,7	100
Netherlands	41,9	66,0	12,1	19,0	9,5	15,0	63,4	100
Romania	15,5	57,4	9,5	35,2	2,0	7,4	27,0	100
Slovakia	6,9	57,3	4,5	37,7	0,6	5,0	12,0	100
Turkey	53,2	51,6	44,4	43,1	5,5	5,3	103,2	100
France	48,9	59,7	16,2	19,8	16,8	20,5	81,9	100
Czech Rep.	9,4	27,2	23,6	67,9	1,7	4,9	34,7	100

TABLE II. SHARE OF RUSSIAN GAS IN THE TOTAL GAS CONSUMPTION OF THE COUNTRY AND SHARE THE SAME GAS IN THE TOTAL VOLUME OF CONSUMED PRIMARY ENERGY AND FUEL OIL IN 2012

Country	Russian gas supply		Share of Russian gas, %	
	Bln m^3	Mtoe	At all gas consumption	At consumption of primary energy and fuel oil
Austria	4,7	5,4	52,2	33,8
Bulgaria	2,5	2,9	92,6	20,8
Hungary	4,8	5,5	49,5	33,4
Germany	30,0	34,5	39,9	15,7
Greece	2,3	2,6	54,8	9,4
Italy	13,6	15,6	19,8	13,3
Netherlands	2,1	2,4	5,8	3,8
Romania	3,8	4,4	28,1	16,2
Slovakia	3,8	4,4	63,3	36,3
Turkey	24,5	28,2	52,9	27,3
France	7,3	8,4	17,2	10,3
Czech Rep.	6,6	7,6	80,5	21,9

The next step is to determine the role of Russian gas to Electricity generation for the country in question. In these countries are used mainly three types of electricity generation capacity (Table III): thermal power plants (TPP), hydro-power plants (HPP) and nuclear power plants (NPP). Together, other types of generating sources (wind power, solar, heat underground sources, etc.) occupy in the balance sheets of electricity production in these countries is not a very big place (the smallest proportion of these sources belong to Turkey - 3%, and the largest in Germany - 18.6%). The share of thermal power plants, including gas-fired plants in the total production of electricity generation, for the countries in question varies considerably - from 9.4% (France) to 84% (Netherlands).

Considering share of electricity generated at thermal power plants and the proportion of electricity generated at thermal power plants due to gas, and the share of Russian gas in the total gas consumption for each country, we determined the proportion of electricity produced at the expense of Russian gas (Table IV). This indicator, firstly, indicating a role of Russian gas in the production of electric energy by each country under normal conditions of export, and, secondly, is an important baseline for assessing the consequences of short supply of Russian gas to the countries.

TABLE III. STRUCTURE OF ELECTRICITY GENERATION IN CONSIDERED COUNTRIES IN 2012

Country	Electricity generation				
	TPP	HPP	NPP	Other	Total
	TWh				
Austria	25,4	39,4	0,0	7,2	72,0
Bulgaria	26,9	3,2	15,8	1,5	47,4
Hungary	15,7	0,2	15,8	2,6	34,3
Germany	382,0	21,2	99,5	114,9	617,6
Greece	46,8	4,4	0,0	5,0	56,2
Italy	206,0	41,5	0,0	48,2	295,7
Netherlands	85,3	0,1	4,0	12,2	101,6
Romania	33,4	12,2	11,5	2,8	59,9
Slovakia	7,2	4,4	15,5	1,3	28,4
Turkey	174,0	57,9	0,0	7,2	239,1
France	52,9	58,3	425,4	23,9	560,5
Czech Rep.	48,5	3,0	30,3	5,8	87,6

TABLE IV. SHARE OF RUSSIAN GAS IN ELECTRICITY GENERATION IN CONSIDERED COUNTRIES IN 2012

Country	Share of electricity generated at TPP, %	Share of electricity generated by gas TPP, %	Share of Russian gas in the total gas consumption, %	Electricity generation by Russian gas	
				TWh	% of total electricity generated
Austria	35,3	60,0	52,2	8,0	11,1
Bulgaria	56,8	12,0	92,6	3,0	6,3
Hungary	45,8	34,0	49,5	2,6	7,7
Germany	61,9	31,0	39,9	47,2	7,6
Greece	83,3	18,0	54,8	4,6	8,2
Italy	69,7	55,0	19,8	22,4	7,6
Netherlands	84,0	78,0	5,8	3,8	3,8
Romania	55,8	40,0	28,1	3,8	6,3
Slovakia	25,4	30,0	63,3	1,4	4,8
Turkey	72,8	28,0	52,9	25,8	10,8
France	9,4	38,0	17,2	3,5	0,6
Czech Rep.	55,4	14,0	80,5	5,5	6,2

It is clear that the share of electricity generated from the Russian gas is the largest in Austria (11.1%) and most minor in France (0.6%). For each country, from consideration, structure of consumption of primary energy and fuel oil in the daily section is defined in Table V.

TABLE V. STRUCTURE OF CONSUMPTION OF PRIMARY ENERGY AND FUEL OIL IN CONSIDERED EUROPEAN COUNTRIES (DAILY SECTION), IN THOUSAND TONS OF OIL EQUIVALENT

Country	Natural gas			Coal		Fuel Oil		Total
	Ttoe	Million m^3	%	Ttoe	%	Ttoe	%	Ttoe
Austria	31,2	27,1	64,7	8,6	17,8	8,4	17,5	48,2
Bulgaria	9,4	8,1	22,4	30,0	71,8	2,4	5,8	41,7
Hungary	33,6	29,2	67,5	12,8	25,8	3,3	6,7	49,8
Germany	260,6	226,6	39,4	338,9	51,2	62,7	9,5	662,2
Greece	14,6	12,7	17,2	51,4	60,7	18,7	22,1	84,6
Italy	238,1	207,0	67,1	69,3	19,5	47,3	13,3	354,7
Netherlands	126,2	109,7	66,0	36,4	19,0	28,6	15,0	191,2
Romania	46,8	40,7	57,4	28,7	35,2	6,0	7,4	81,5
Slovakia	20,8	18,1	57,3	13,7	37,7	1,8	5,0	36,3
Turkey	160,5	139,5	51,6	133,9	43,1	16,6	5,3	311,0
France	147,3	128,1	59,7	48,8	19,8	50,6	20,5	246,7
Czech Rep.	28,4	24,7	27,2	71,0	67,9	5,1	4,9	104,6

The transition from the annual consumption volumes to the daily volumes of consumption have been done through factor of seasonal irregularity in gas consumption in the countries.

$$Q^{day} = \frac{Q^{year}}{365} * k_{si} \ , \quad (1)$$

Q^{day} – daily volumes of consumption (gas, coal, fuel oil);

Q^{year} – annual consumption volumes (gas, coal, fuel oil);

K_{si} – factor of seasonal consumption irregularity.

III. POSSIBLE REDUCTION OF GAS SUPPLY

In calculating of the hypothetical situation with the cessation of gas supply, it makes sense to talk about period of the early spring, when gas consumption is still considerably and underground gas storage can no longer work on the value of the maximum gas extraction. The situation in European countries in this case is similar and the analysis shows that the factor of seasonal consumption irregularity at this time close to the value of 1.1. That value of this factor accepted for further calculations.

By means of software complex "Oil and Gas", that described [4, 5], was modeled situation when stops export of gas from Russia to Europe through Ukraine.

To solve the problem of assessing the state of the system after a disturbance is used the criterion of the optimal flow distribution. It implies a minimum gas shortage at the consumer at minimum costs for the delivery of gas to consumers. It means to solve the task of maximum flow of minimum cost. This task, in this case, is solved by using the algorithm of Busacker and Gowen, described in [3]. Furthermore, the use of software complex "Oil and Gas" allows defining required daily gas extraction from the underground storage facilities of the European gas network. The mathematical expression of the task:

$$\max f \quad (2)$$

with following conditions

$$\sum_{i \in N_j^+} x_{ij} - \sum_{i \in N_j^-} x_{ji} = \begin{cases} -f, j = s \\ 0, x \neq s, t \\ f, j = t \end{cases} \quad (3)$$

$$0 \leq x_{ij} \leq d_{ij}, \text{ for all } (i, j) \quad (4)$$

$$\sum_{(i,j)} C_{ij} x_{ij} \rightarrow min \quad (5)$$

N^+_j – a subset of the "incoming" in node j arcs;

N^-_j – a subset of the "emerging" arcs from node *j*;

f – the value of the total flow through the network;

x_{ij} – flow through arc *(i, j)*;

s - gas source;

t - gas consumer;

d_{ij} – restrictions for the flow of the arc *(i, j);*

C_{ij} – specific expenses for gas transportation.

Solution of this problem allowed identify possible shortages of Russian gas to European countries in considered scenario, Table VI. Also, we compare the calculated data on possible short-ages of gas under the conditions of this scenario with the initial situation prior to the emergence situation like this, Table VII.

TABLE VI. POSSIBLE SHORTFALLS OF RUSSIAN GAS TO EUROPEAN COUNTRIES DUE TO THE CESSATION OF GAS EXPORTS THROUGH UKRAINE (DAILY SECTION)

Country	Consumption	Supply	Shortage
	mln m^3		%
Austria	12,9	0	100
Bulgaria	8,1	0	100
Hungary	13,2	0	100
Germany	82,2	82,2	0
Greece	6,3	0	100
Italy	37,3	0	100
Netherlands	5,8	5,8	0
Romania	14,6	5,6	38,4
Slovakia	10,4	0	100
Turkey	67,1	32,8	48,9
France	20,0	0	100
Czech Rep.	18,1	0	100

TABLE VII. VOLUMES OF GAS SUPPLIES FROM RUSSIA AND THE TOTAL VOLUME OF GAS CONSUMPTION FOR THE COUNTRIES IN QUESTION ON THE DAY BEFORE THE BEGINNING OF THE PERIOD OF SHORT SUPPLYING AND SHORT SUPPLY OF GAS UNDER THE CONDITIONS OF DESCRIBED SCENARIO, MLN M^3 /DAY

Country	Before shortages		Short supply of gas	
	Total gas consumption	Gas supply from Russia	Volumes of shortages	Gas consumption
Austria	27,1	12,9	12,9	14,2
Bulgaria	8,1	6,8	6,8	1,3
Hungary	29,2	13,2	13,2	16,0
Germany	226,6	82,2	0,0	226,6
Greece	12,7	6,3	6,3	6,4
Italy	207,0	37,3	37,3	169,7
Netherlands	109,7	5,8	0,0	109,7
Romania	40,7	10,4	9,0	31,7
Slovakia	18,1	10,4	10,4	7,7
Turkey	139,5	67,1	34,3	105,2
France	128,1	20,0	20,0	108,1
Czech Rep.	24,7	18,1	18,1	6,6

The final scale of reduction of the supply of primary energy and fuel oil in the whole of each country, in the power of the country and in total – to all other consumers of the country, and reducing of the production of electricity for the country presented in the summary Table VIII.

TABLE VIII. LEVELS OF REDUCED SUPPLIES OF PRIMARY ENERGY AND FUEL OIL TO CONSUMERS OF EUROPEAN COUNTRIES AND THE DECREASE IN ELECTRICITY GENERATION (IN ALL COLUMNS -% OF DELIVERIES TO EXPORT VIOLATIONS)

Country	Deficit of Russian gas	Deficit of primary energy and fuel oil in the whole	Deficit of primary energy and fuel oil to the electricity	Deficit of primary energy and fuel oil to other consumers	Reducing of the electricity generation
Austria	100	33,8	31,3	36,9	11,1
Bulgaria	100	20,8	11,1	41,3	6,3
Hungary	100	33,4	16,8	41,7	7,7
Germany	0	0,0	0,0	0,0	0,0
Greece	100	9,4	9,9	8,8	8,2
Italy	100	13,3	10,9	17,1	7,6
Netherlands	0	0,0	0,0	0,0	0,0
Romania	38,4	6,2	4,3	7,6	2,4
Slovakia	100	36,3	19,0	40,9	4,8
Turkey	48,9	13,4	7,2	22,1	5,3
France	100	10,3	6,5	11,3	0,6
Czech Rep.	100	21,9	11,3	32,0	6,2

As a result, in terms of reducing the supply of primary energy and fuel oil in the whole country (Table VIII) among the considered countries with a decrease in gas supplies from Russia to them most affected Slovakia - 36.3%, Hungary - 33.4% and Austria - 33.8%. Least affected the Netherlands and Germany - there are no shortages, Greece - 9.4%, Romania - 6.2%.

Shortages of primary energy and fuel oil in power and other consumers to a greater extent may affect on Austria, Hungary and Slovakia. Accordingly, while reducing gas supplies from Russia decrease of electricity production in Austria could reach 11.1%; in Greece - 8.2%; in Hungary - 7.7%. At the same time, in France, these shortages of Russian gas almost had no impact on level of electricity production.

The rest of the countries in question are located between the two groups of countries listed above. We can assume that reduction of gas supplies from Russia for these countries can cause a not so significant decrease in the production of electricity, it is: Bulgaria - 6.3%; Czech Republic - 6.2%; Turkey - 5.3%; Slovakia - 4.8%; Romania - 2.4%.

In order to soften the situation with short delivery of primary energy and fuel oil to these countries could be taken the following moments:

- choice a variant of the gas distribution between electricity and other customers for the period of violations of its exports;
- mutual assistance of European countries - importers of Russian gas, which is expressed in the redistribution of gas flows between countries;
- replacement of short supply of natural gas by increasing consumption of coal and fuel oil, as well as being due to a certain decline in exports and increase in imports of certain types of primary energy and fuel oil.

IV. CONCLUSION

The article highlights the importance of timely deliveries of Russian gas to European countries - importers. It is shown that European consumers can suffer in the considered situation. Thus, all parties would be easier to ensure the normal operation of related gas transfer network, avoiding situations such as those described in the article, especially for economic and political reasons.

REFERENCES

1. BP Statistical Review of Word Energy 2013 – http://www.bp.com/statisticalreview.
2. Energy Information Administration. Official Energy Statistics from the U.S. Government – http://www.eia.doe.gov.
3. Ford L.R., Fulkerson D.R. 1962. *Flows in networks*. Princeton NJ: Princeton University Press.
4. Senderov S.M., Edelev A.V. 2002. “Method of determining the weak places in the unified gas supply system and a choice of ways to overcome the emergency gas supply consumers” *Izvestiya RAN. Energetika*, 4: 57-62.
5. Voropai N.I., Senderov S.M., Edelev A.V. 2012. Detection of “bottlenecks” and ways to overcome emergency situations in gas transportation networks on the example of the European gas pipeline network / Energy 42, pp. 3-9. (DOI information: 10.1016/j.energy.2011. 07.038).