Resilience Evaluation of the South East European Natural Gas Routes System

Catastrophe

Naim Afgan, Dejan Cvetinovic

Abstract—Natural Gas Supply system in South-East Europe is a complex system designed to supply the need of the natural gas for the South-East European countries. The Natural Gas South East European system comprises four potential routes. It includes Russian gas pipelines, South stream, Nabucco route, and Adriatic route. Total capacity of the South East European Natural Gas is around 208 bcm/y. Resilience evaluation of the South East European Natural Gas system includes formation of the potential options of resilience indexes for the respective sudden change of the system supply as the result of interruption of the individual route. In this evaluation it is anticipated a following rupture of individual routes: a. Change of the total gas supply due to rupture of Russian gas pipeline; b. Change of the total gas supply due to rupture of South stream gas pipeline; c. Change of the total gas supply due to rupture of Nabucco gas pipeline; d. Change of the total gas supply due to rupture of Adriatic gas pipeline. The assessment of sudden change of gas supply system is based on the rating of individual option measured by the resilience index for each case.

Index Terms—natural gas supply system, Russian gas pipeline, South stream gas pipeline, Nabucco gas pipeline, Adriatic gas pipeline, resilience index.

I. INTRODUCTION

Natural gas supply system in South-East Europe [1,2,3] is lately diversified in the several potential options. Presently only single route exist to ensure stable gas supply to most of the South East European countries. The planning of natural gas supply system reflects a common interest of the countries and their interest for the gas supply system. With the respective mutual agreement on the individual projects the planning stage of every natural gas route is verified as the part of the common strategy. The organization of the specific route is joint agreement of parties and the study of geographical and cost validation of the respective route. It is of special interest the cost of every routes. It is recognized that the future projects: Nabucco natural gas pipeline and South Stream natural gas pipeline are planned as the potential transport of route for the South European and Central European countries of natural gas supply system. Both these routes are in advanced planning stage with mutual agreement between countries actively participating in the design and construction of the routes. The South East Europe Pipeline (SEEP), [4] proposed in late 2011, was the pipeline carrying Azeri gas to European markets. Compared to its competitors in the Southern Corridor concept it goes furthest in terms of optimality for all the parties involved. The combined advantages of its size, scalability, usage of existing gas infrastructure in Europe and direction, promises a more reasonable economic and political value for the Shah Deniz Consortium, Azerbaijan, Turkey and Europe, while posing challenge to Russia. Many new LNG import terminals have been proposed in recent years in response to the increase in LNG demand. There are currently fourteen LNG import terminals operational in Europe (including Turkey) [5]. Other terminals in Belgium, France, Italy, Spain and the United Kingdom are under construction or being expanded and are due to become operational in the next several years. Some of these proposed terminals are sponsored by companies developing upstream liquefaction in order to secure downstream market access for their LNG and/or by power utilities seeking new gas supplies [6]. In order to introduce the versatility of gas resources in the natural gas supply system in South East Europe [7,8] there have been several major gas supply route, among those are: Russian gas route, South East route, Nabucco Route and Trans Adriatic route.

A. Major Russian gas route to Europe

Russia is the largest natural gas source supplying Central and South East Europe through the Yamal pipeline geographically it is situated as the main gas supply through Belorussia and Poland to run parallel to the first Yamal and would have a similar capacity. In this context, Belarus is an important transit country for Russian gas deliveries to Europe, with the country's natural gas transportation monopoly Beltransgaz managing a total of more than 2000 kilometers of natural gas pipelines. The total capacity for the two Yamal lines is foreseen at 65.7 billion cubic meters per year. Fig.1 shows the Yamal pipelines for natural gas supply to Europe [9]. The Yamal link, designed to connect Slovakian infrastructure, is under consideration although, at present, the degree of priority of this project is unclear. The project to increase the capacity of the existing Yamal pipeline through Belorussia to Poland remains an important priority. This project of 1-2 billion Euros would allow for the increase in the export capacity from the existing Gazprom fields and would thus contribute directly to the objectives pursued in the context of the EU/Russian energy dialog. The natural gas cost from the Yamal fields is estimated to be in excess of 20 Billion Euros. There is little doubt that in view of substantial potential for energy savings in Russia as well as the potential production capacity of various smaller fields,
being developed by the independent oil company, Russia will be able to increase its export of natural gas to Europe without the full development of the Yamal fields, at least within the foreseen future.

**Fig 1. Russian pipeline [9]**

**B. South Stream route**

The South Stream project is aimed at strengthening the European energy security [10]. It is another real step toward executing the Gazprom strategy to diversify the Russian natural gas supply routes. The new gas pipeline system is meeting the latest environmental and technological requirements will significantly raise the energy supply security of the entire European continent. The project provides the South Stream’s offshore section to run under the Black Sea from the Russian coast (Beregovaya compressor station) to the Bulgarian coast. The total length of the offshore section will be around 900 km, maximum depth – over two km and full capacity – 63 bcm/y. In November 2006 Gazprom and Eni entered into the Strategic Partnership Agreement providing Gazprom with the opportunity to directly supply Russian gas to the Italian market starting from 2007. Gas supply volumes will be gradually increased to 3 billion cubic meters per annum by 2010. Under the Agreement for The Russian gas supply to Italy have been extended till 2035.

**Fig 2. South Stream pipeline [10]**

**C. Nabucco route**

The Nabucco Route is a natural gas pipeline project for Turkey, Bulgaria, Romania, Hungary and Austria [11]. The extent of detailed planning, and in particular its development by prospective gas importers, makes it look increasingly probable that during the next few years we will see the development of at least one of the major pipeline systems for the delivery of Eurasian gas to Europe via Turkey. The geographic locations of Turkey, Bulgaria, Romania, Hungary and Austria are connected to the major producers/suppliers of natural gas in the Caspian Sea region. The major consumers of energy in Turkey and Europe make South East Europe an important transit route for Russian, Caspian and Middle East natural gas supplies. The total capacity of the Nabucco project is estimated at 20-30 billion cubic meters with a total of 3,630 kilometers of pipelines. It will meet the market in North, Central and West Balkan regions. Austrians OMV develop the Nabucco project in partnership with the Turkish state pipeline company, Botas, the Hungarian MOL Transmission PLC, the Bulgarian Bulgas and the Romanian Transgas. Transit countries would use 8-10 bcm/y, so that the delivery to Baumgarten would be around 17-20 bcm/y. Partners in the project have all agreed to meet at least part of their domestic demand by means of the Nabucco pipeline.

**Fig 3. Nabucco Pipeline [10]**

**D. Trans-Adriatic route**

Current discussions on opening the Southern Gas Corridor often overlook the South Eastern Europe region which is highly dependent on a single energy supplier. For example, Bosnia and the Former Yugoslav Republic of Macedonia rely on Russia for 100% of all domestic demand, Serbia for 88%, and Croatia 39%. Stimulated by solid economic growth – around 2-5% increase of GDP a year the South Eastern Europe (SEE) market will register an increasingly higher energy demand in the near future. The region’s collective aspiration to join the EU means that this region will also need a more environmentally balanced energy portfolio [12, 13].

**Fig 4. Trans Adriatic pipeline [16]**

Trans Adriatic Pipeline (TAP) [14,15] offers possibility to connect the region to the abundant supplies in the Caspian basin, by interconnecting with the Ionian Adriatic Pipeline (IAP). Moreover, TAP’s ability to expand its capacity from 10 to 20 bcm/y means that further supply diversification will be possible once additional gas sources come on stream. TAP can enhance the development of the gas market in South Eastern Europe by enabling the realization of the Ionian...
Adriatic Pipeline, a project which has been designated by the Energy Community as a priority for the region. This pipeline is aiming to connect the existing and planned gas transmission systems of Croatia, Albania, Montenegro and Bosnia & Herzegovina, through a TAP tie-in, the IAP would benefit from new and abundant gas supplies. TAP will provide countries connected through the IAP with access to neighboring networks in Italy and Greece, and then via these networks to additional pipeline systems in the rest of Europe. This will favor market integration in the region as well as render the markets more resilient in the event of a supply emergency. Several countries in the SEE region currently rely on carbon-intensive energy sources, particularly coal and oil, to meet a significant percentage of their energy needs. Yet, gas remains the cleanest of fossil fuels, so TAP will contribute to improving environmental conditions in the SEE region.

II. NATURAL GAS SUPPLY DEMAND

Before analyzing the natural gas supply demand, it is of interest to verify the basic economic and energy data for the South-East European countries. Data presented in the Table I are corresponding to 2009.

A. Capacity of natural gas system:
Total capacity of the gas streams will include
- Russian stream pipeline: 65.7 bcm/y
- South stream pipeline: 63 bcm/y
- Nabucco stream pipeline: 30 bcm/y
- Adriatic stream pipeline: 50 bcm/y

B. Pipeline length:
- Russian stream pipeline: 2000 km
- South stream pipeline: 900 km
- Nabucco stream pipeline: 900 km
- Adriatic stream pipeline: 1200 km

III. VULNERABILITY

Vulnerability of south-east gas supply system have several points which are important to be taken into a consideration in the assessment of the potential disruption of the gas supply system [17]. In this evolution it will be anticipated that the main disruption of the gas supply system will be result from the sudden change of the supply system capacity as the result of pipeline rupture. In this evaluation a following cases will be taken into a consideration. Disruption of Russian gas stream
- Disruption of South stream
- Disruption of Nabucco stream
- Disruption of Adriatic stream

IV. RESILIENCE

The essential tool for the validation is the definition of the resilience [18, 19] of gas system. The resilience of the gas supply system can be defined as

\[ R_i = w_i \int_{t=0}^{t=\Delta t} (1 - q_i) dt \]  \hspace{1cm} (1)

Where
- \( w_i \) - probability of the sudden disruption of indicator,
- \( \Delta t \) - time interval for indicator recovery.

In this analysis we will focus our attention on the following cases:

A.) Disruption of Russian pipeline
B.) Disruption of South stream pipeline
C.) Disruption of Nabucco pipeline
D.) Disruption of Adriatic pipeline

A.) Disruption of Russian pipeline

In the evaluation of specific cases the main disruption is defined as the sudden change of gas flow in the system. In the case A it is anticipated sudden disruption of the Russian pipeline. As the total capacity of the gas supply system is 208.7 bcm/y, the sudden disruption of Russian pipeline will introduce \( \Delta q = 31.6 \% \) deficiency of the gas supply system. If the recovery of the system will take about \( \Delta t = 24 \) h, the resilience of this sudden change can be defined by the integral

\[ R_{RUS} = w_{RUS} \int_{t=0}^{t=\Delta t} (1 - q_{RUS}) dt \]  \hspace{1cm} (2)

Where
- \( R_{RUS} \) - resilient index for Russian pipeline rupture,
- \( w_{RUS} \) - probability of Russian pipeline indicator,
- \( \Delta t \) - recovery time for Russian pipeline indicator,
- \( q_{RUS} = Q_{RUS}/Q_{SUPP} \)

With assumption that the recovery of flow indicator is linear function of time then the resilience index is

\[ R_{RUS} = \frac{1}{2} w_{RUS} (\Delta q_{RUS} \Delta t_{RUS}) \]  \hspace{1cm} (3)

\[ q_{RUS}=100 \% \]

\[ q_{RUS}=65 \% \]

\[ t_i \]

\[ t_f \]

Fig 5. Graphical presentation of Resilience Index for sudden change of gas flow in gas supply system due to rupture of Russian pipeline

As the Russian pipeline comprise the largest part in the natural gas supply in the region the potential rupture of this pipeline will substantially effect it economy. For this reason it is paramount importance to have essential control of the potential failure of the natural gas supply system. In this respect a full control and assessment of the resilience index change due to the rupture of the Russian pipeline. Since this rapture will imply \( \Delta q = 31.8 \% \) of the total gas supply of the system with the delay in the full recovery \( \Delta t = 24 \) h it may lead
to the catastrophic deficiency of the natural gas system in the region.

**B. Disruption of South Stream pipeline**

As the total capacity of the gas supply system is 208.7 bcm/y the sudden disruption of South stream pipeline will introduce 30.2% deficiency of the gas supply system. If the recovery of the system will take about 48 h the resilience of this sudden change can be defined by the integral

\[
R_{SS} = w_{SS} \int_{t=0}^{t=t_{SS}} (1-q_{SS}) \, dt
\]

(4)

Where

- \( R_{SS} \) – resilient index for South stream pipeline rupture,
- \( w_{SS} \) – probability of South Stream pipeline indicator,
- \( t_{SS} \) – recovery time for South Stream pipeline indicator,
- \( q_{SS} = Q_{SS}/Q_{SIS} \)

With assumption that the recovery of flow indicator is linear function of time then the resilience index is

\[
R_{SS} = \frac{1}{2} w_{SS} (\Delta q_{SS} \Delta t_{SS})
\]

(5)

\( q_{SS} = 100\% \quad q_{SS} = 0\% \)

Fig 6. Graphical presentation of Resilience Index for sudden change of gas flow in gas supply system due to rupture of South steam pipeline

**C. Disruption of Nabucco pipeline**

In the evaluation of specific cases the main disruption is defined as the sudden change of gas flow in the system. In the case C it is anticipated sudden disruption of the Nabucco pipeline. As the total capacity of the gas supply system is 208.7 bcm/y the sudden disruption of Nabucco pipeline will introduce 14.4% deficiency of the gas supply system. If the recovery of the system will take about 36 h the resilience of this sudden change can be defined by the integral

\[
R_{NA} = w_{NA} \int_{t=0}^{t=t_{NA}} (1-q_{NA}) \, dt
\]

(6)

Where

- \( R_{NA} \) – resilient index for Nabucco pipeline rupture,
- \( w_{NA} \) – probability of Nabucco pipeline indicator,
- \( t_{NA} \) – recovery time for Nabucco pipeline indicator,
- \( q_{NA} = Q_{NA}/Q_{SIS} \)

With assumption that the recovery of flow indicator is linear function of time then the resilience index is

\[
R_{NA} = \frac{1}{2} w_{NA} (\Delta q_{NA} \Delta t_{NA})
\]

(7)

Nabucco system for the natural gas supply system is verified as the reference to the new natural gas supply system in the new energy strategy in European Union. It has also strong political emphasize since it bears active role in the independency of the Russian gas supply. In this respect the resilience index of Nabucco pipeline rupture act as the safety factor in the assessment of the natural gas supply system of the West Europe. The sudden change of gas supply flow due to the rupture of the Nabucco pipeline will affect the total gas supply with \( \Delta q = 14.4\% \). It is anticipated that the recovery of the system will require \( \Delta t = 36 \) h.

**D. Disruption of Trans Adriatic pipeline**

In the evaluation of specific cases the main disruption is defined as the sudden change of gas flow in the system. In the case D it is anticipated sudden disruption of the Nabucco pipeline. As the total capacity of the gas supply system is 208.7 bcm/y the sudden disruption of Nabucco pipeline will introduce 24% deficiency of the gas supply system. If the recovery of the system will take about 24 h the resilience of this sudden change can be defined by the integral

\[
R_{AS} = w_{AS} \int_{t=0}^{t=t_{AS}} (1-q_{AS}) \, dt
\]

(8)

Where

- \( R_{AS} \) – resilient index for Adriatic pipeline rupture,
- \( w_{AS} \) – probability of Adriatic pipeline indicator,
- \( t_{AS} \) – recovery time for Adriatic pipeline indicator,
- \( q_{AS} = Q_{AS}/Q_{SIS} \)

With assumption that the recovery of flow indicator is linear function of time then the resilience index is

\[
R_{AS} = \frac{1}{2} w_{AS} (\Delta q_{AS} \Delta t_{AS})
\]

(9)

Fig 7. Graphical presentation of Resilience Index for sudden change of gas flow in gas supply system due to rupture of Nabucco pipeline

Fig 8. Graphical presentation of Resilience Index for sudden change of gas flow in gas supply system due to rupture of Adriatic steam pipeline
The Adriatic route for the natural gas supply from the Caspian region is the strategic pipeline for the development of the new natural gas resource. Since it has the aim to introduce a new natural gas resource in the South European region it requires special attention to the resilience index of the Adriatic pipeline. The Adriatic pipeline rupture with $\Delta q = 24\%$ sudden change of the capacity and $\Delta t = 24\text{ h}$ for the recovery time.

V. DISCUSSION

From the graphical presentation of the Resilience Indexes for individual pipeline rupture of the Natural gas supply system it can be noticed that the Resilience index for every individual case is the measuring parameter for the potential failure of the system. It is evident that the difference of the failure can be verified with appropriate Resilience index. The failure of the Russian gas pipeline defined with the respective Resilience Index is the largest failure in the Gas supply system. Since it can be recovered within 24 hours it may be considered as the failure without potential disaster to gas supply system. The failure of South Stream pipeline has limited consequences to the natural gas supply system. It is of interest to notice that the South Stream pipeline rather is a short pipeline and limited capacity, the potential failure has limited influence to the Natural gas supply system. Nabucco gas pipeline is considered of interest to only limited number of countries since it has rather limited capacity in comparison to the other pipeline within the gas supply system. The potential failure of Nabucco pipeline has rather limited effect to the total natural gas supply system. In this respect this pipeline has small effect to the Natural gas supply system for the South East and Central Europe. The Trans Adriatic pipeline is a new pipeline and is opening a new vision of for the development of the Natural gas supply for the South East Europe. This pipeline is connected to the Turkmenistan and Azerbaijan natural gas resources. Besides supply natural gas to the Italian market. At this point it has to be mentioned that the LNG Terminal in Neum (Bosnia and Herzegovina) will open additional resources (Algeria, Qatar, Nigeria and Egypt) to be used for the supply of the Natural gas supply system.

VI. CONCLUSION

Potential natural gas supply system has been in the past very dependent on the Russian gas recourses. The increase of demand for the new gas resources has open a new natural gas market venue in the development the natural gas utilization. In particular, the utilization of natural gas for the electricity production has gained high support for the clean air power plants. The failure of the gas supply system is closely related to the different causes. It may be result of the diversion on energy system, different natural disasters (earthquake, hurricanes, and tornado) human negligence etc. In evaluation of the potential failure it is of great interest the development appropriate procedure for the prediction of the eventual failure. These procedures are based on the formation of the Resilience Index for every individual potential failure. For the assessment of the gas supply system it is of special interest to determine Resilience index for the failure reflecting rupture of the individual gas pipeline. In this respect if the resilience index lower than the critical value of the resilience index the failure has to be considered as potential catastrophe even.

VII. ACKNOWLEDGMENT

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AUTHOR’S PROFILE

First Author Naim Afgan, Emeritus professor, Instituto Superior Tecnico, Lisbon, Portugal. Member of Academy of Science and Art of Bosnia and Herzegovina, Sarajevo.

Second Author Dejan Cvetinovic, Scientific associate, Institute of Nuclear Energy Vinca, Belgrade, Serbia.

APPENDIX

Table 1. South East Europe Basic Economic & Energy Information (2009) [16]

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (Million)</th>
<th>GDP (PPP) (USD Billion)</th>
<th>FDI (% GDP)</th>
<th>Installed Electricity Capacity (MW)</th>
<th>Oil Consumption (bl/day)</th>
<th>Gas Consumption (bcm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albania</td>
<td>3.2</td>
<td>19.9</td>
<td>4.2</td>
<td>1.590</td>
<td>33,000</td>
<td>0.02</td>
</tr>
<tr>
<td>Bosnia &amp; Herzegovina</td>
<td>4.6</td>
<td>28.2</td>
<td>5.48</td>
<td>4.341</td>
<td>27,500</td>
<td>0.31</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>7.2</td>
<td>90.1</td>
<td>7.15</td>
<td>11.360</td>
<td>120,000</td>
<td>3.5</td>
</tr>
<tr>
<td>Croatia</td>
<td>4.4</td>
<td>76.5</td>
<td>6.94</td>
<td>4.460</td>
<td>106,000</td>
<td>3.1</td>
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<tr>
<td>Cyprus</td>
<td>0.75</td>
<td>17.2</td>
<td>9.0</td>
<td>1.240</td>
<td>61,000</td>
<td>0</td>
</tr>
<tr>
<td>FYROM</td>
<td>2.1</td>
<td>9.2</td>
<td>2.03</td>
<td>1.581</td>
<td>21,000</td>
<td>0.05</td>
</tr>
<tr>
<td>Greece</td>
<td>11.2</td>
<td>357.5</td>
<td>0.42</td>
<td>14.300</td>
<td>428,860</td>
<td>4.25</td>
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<td>0.67</td>
<td>6.6</td>
<td>11.0</td>
<td>0.883</td>
<td>5,000</td>
<td>0</td>
</tr>
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<td>Romania</td>
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<td>161.5</td>
<td>6.0</td>
<td>21.360</td>
<td>225,000</td>
<td>16.9</td>
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<td>89.5</td>
<td>10.0</td>
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<td>5.6</td>
<td>110.926</td>
<td>1.759.050</td>
<td>69.95</td>
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