IMPACT OF NORD STREAM ON PARALLEL GAS TRANSMISSION INFRASTRUCTURE IN SLOVAKIA

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1. Background

The transmission system operated by Eustream has proven to be a reliable part of the European gas transmission infrastructure (Fig. No. 1), allowing gas transportation from producer countries to the European gas markets. Eustream operates a high-pressure gas transmission system that is interconnected with major European trunk lines in Ukraine, the Czech Republic and Austria.

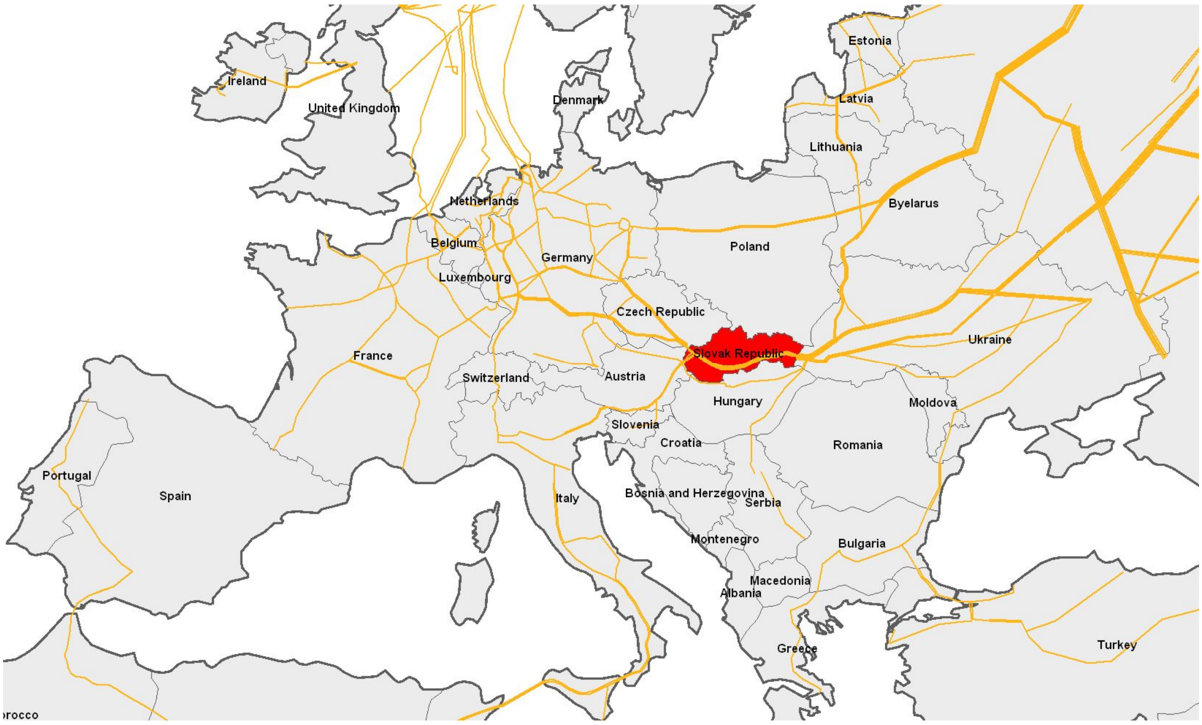


Fig. No.1. Slovak transmission system and major European gas transmission infrastructure before Nord Stream

The Slovak transmission system consists of four to five parallel pipelines, mostly 1200/1400 mm in diameter with an operating pressure of 73 bars. The pressure differential needed for continuous gas flow is ensured by four large compressor stations with an aggregate power of more than 1000 MW. The most important station is located at Veľké Kapušany at the Ukrainian-Slovak border. With a total power of nearly 300 MW, it is the biggest compressor station in the EU, allowing an entry flow of almost 300 million cubic meters per day. The annual capacity of the system exceeds 90 billion cubic meters.

Access to the transmission system is entry-exit based. For entering and exiting the system customers can choose from the following four entry/exit points (Fig. No. 2):

- A - Veľké Kapušany (border point between the Slovak Republic and Ukraine),
- B - Lanžhot (border point between the Slovak Republic and the Czech Republic),
- C - Baumgarten (border point between the Slovak Republic and Austria),
- D - Domestic point (virtual aggregated interconnection to and from domestic storage and distribution networks).

Fig. No.2. Existing Entry/Exit points of the Slovak transmission system

The configuration of the transmission system is adjusted optimally with regard to our present conditions. However, these conditions are developing and changing in relation to continuous changes in legislation and transmission contracts. The transmission contracts and resulting expected flow-rates are influenced by new neighbouring pipeline systems, mainly the Nord Stream and the related projects. Based on the schedule, the first of the Nord Stream's twin pipelines was ready to transport Russian gas directly to the Europe in the last quarter of 2011. When fully operational in the last quarter of 2012, the twin pipeline system will supply 55 billion cubic meters of gas per year. From the perspective of the Slovak transmission system, this new capacity will reduce the capacity demand mainly in the direction of Veľké Kapušany (A) entry point and Lanžhot (B) exit point.

2. Objectives

Considering the fact that the requirement of maximal daily transmission capacity in the future will be lower than today, the new transmission contracts brought along the question of optimal configuration of the transmission system. In addition, another impact of Nord Stream and the related projects is that the distribution of flows in the main directions of gas transmission will change significantly. Decreasing of transmission in the direction from A to B will lead to uneven utilization of the last part of the pipeline network before the entry/exit points B and C. As a result of the reduced and partial redirection of transmission from the Czech Republic (B), a part of the system will be less utilized in this direction, and vice versa, in the direction to Austria (C) the transmission network will be utilized more.

In order to address the impact of Nord Stream and to adapt the system for the new conditions the overall optimization of the gas transmission infrastructure was launched in 2005. The optimization was divided into following two main parts:

- Optimization of the strategic pipeline infrastructure (2005 - 2008)
- Optimization of the compressor fleet (2005 - 2016)

The objectives of the system optimization are as follows:

- To ensure compliance with legislation on the new emission limits (much stricter) of compressor units.
- To increase current system flexibility over the long term perspective.
- To prepare the concept of the whole transmission network in order to adapt its design to new conditions with lower anticipated flows.

2. Method of optimization of the strategic pipeline infrastructure

The aim of optimizing the strategic pipeline infrastructure was to address the impact of Nord Stream on the expected uneven utilization of the pipeline network. Uneven utilization of the pipeline network puts emphasis on the transmission system control and the flexibility of the operation. The main target of the optimization was to utilize the full potential of the installed pipelines in order to increase the flexibility of the gas transmission in the future. In order to create a flexible tool for the dispatching centre regarding the non-steady nature of the gas transmission there was implemented a detailed analysis of the interdependence of technical capacities.

In general, the technical capacity is a key system parameter which is represented by mutual interaction of the sources of energy for gas transmission (compressor stations) and energy consumers (mainly pipelines). This interaction leads to restoring of the necessary pressure for transportation of gas before each section of pipelines which is provided by the compressor stations (e.g. Fig. No.4).

The comprehensive analysis of the above mentioned interaction, which leads to the value of the technical capacity and the other key system indicators, is based on the simulation software. In addition to the geometric values of the pipelines (lengths, diameters) the effect of inclined positions, the roughness of the pipes (influence on the pressure drop) and the equation of state for real gas are taken into account in order to provide accurate determination of the key system indicators. The thermal dynamics module also calculates heat transfer between the pipeline and its surroundings and the Joule-Thomson effect. Calculation of the compressor station parameters is based on the detailed compressor model which includes detailed presentation of compressor performance curves, drives and gas coolers with all the restrictions involved. Multi-compressor operation in any type of series or parallel configuration is simulated with realistic load distribution control. Model also includes an air temperature influence on the available maximum power of the compressor drive.

The simulation of gas transmission, which is a basic element of optimization, is based on non-linear partial differential equations. These equations describe the conservation of mass, momentum and energy. The behavior of the real gas is described by an equation of state including real composition of the gas. The pressure drop caused by flow resistance is calculated by utilization of the friction factor which depends on roughness of the pipeline, pipeline diameter, flow velocity and gas properties.

In order to prove the accuracy, simulation results (pressures at all nodes of the network and all flows through network elements, such as pipes and compressors) are continuously compared to real data in order to prove the reliability of the calculations. This approach regarding technical capacity calculation is applied in order to provide as much available capacity to the market as possible.

The complex optimization of the strategic pipeline infrastructure is based on experience and method of operating the transmission system in the past taking into account future requirements, capacity demand and the expected flowrates. Due to the unified hydraulic mode of the transmission system (Fig. No. 3) the last compressor station worked with one output pressure, whereas at two main border delivery stations B and C the contracted pressures are different.

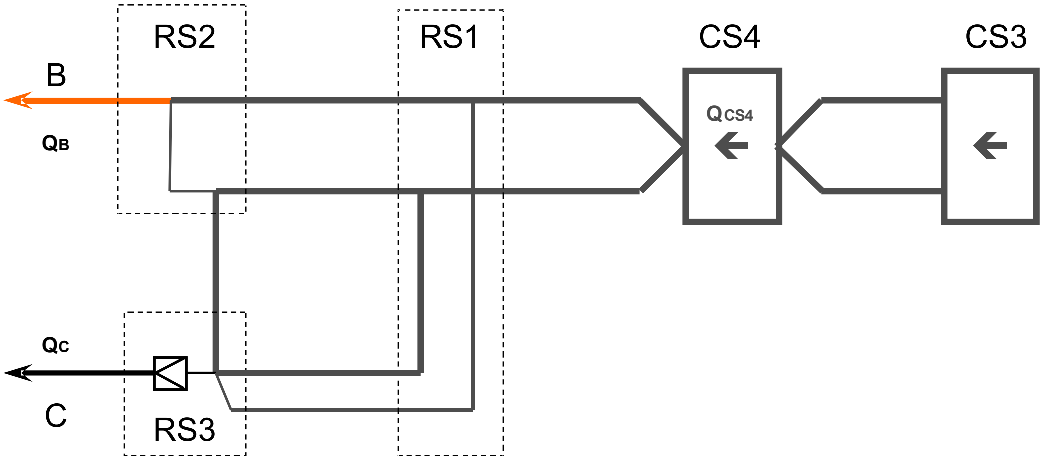


Fig. No.3. Scheme of the unified hydraulic mode

Therefore under the unified hydraulic mode it was not possible to observe precisely both of the contracted pressures concurrently. Due to that the last compressor station was controlled to observe the contracted pressure in one of the outputs (e.g. B), whereas in the second output (C) the pressure was higher than contracted by the value of the reserve, which, however, was not under our control (see fig. No. 4).

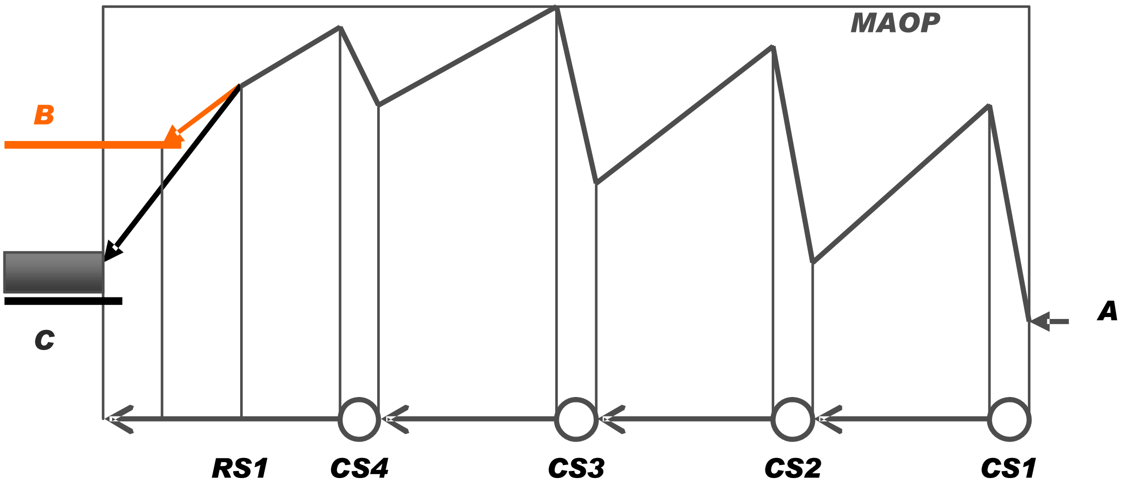


Fig. No.4. Course of pressures at unified hydraulic mode

In this way the above mentioned reserve or pressure surplus was decreased in control valves at the regulation station RS3 (see fig. No. 3) because of the maximum operating pressure of the downstream pipelines.

The main result and recommendation of the optimization process was to split the strategic pipeline infrastructure into two parts dedicated for the main transmission directions, B and C respectively. The goal of hydraulic splitting of the transmission system is just to enable observance of the contracted pressure in both outputs B and C concurrently with an option of controlling the amount of necessary reserve with respect to expected transportation by the system. In this way it is possible to optimize the transmission by the system with respect to frequently changing conditions of transmission without necessity to change the mode of compressor stations within a certain interval of the above mentioned changes.

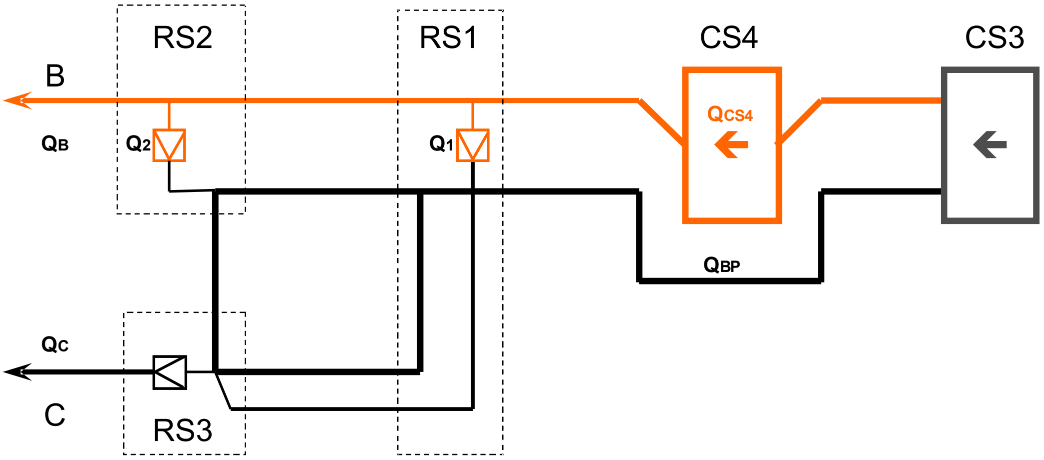


Fig. No.5. Scheme of hydraulic splitting of the transmission system

In the split system (Fig. No. 5) the compressor station CS3 compresses and controls the flow of gas in both directions, however the emphasis is laid on observance of the contracted pressure at C. The compressor station CS4 compresses and controls the flow of gas only in direction to B, with impact on observance of the contracted pressure at B. The volume of gas in direction to C flows through the bypass at CS4.

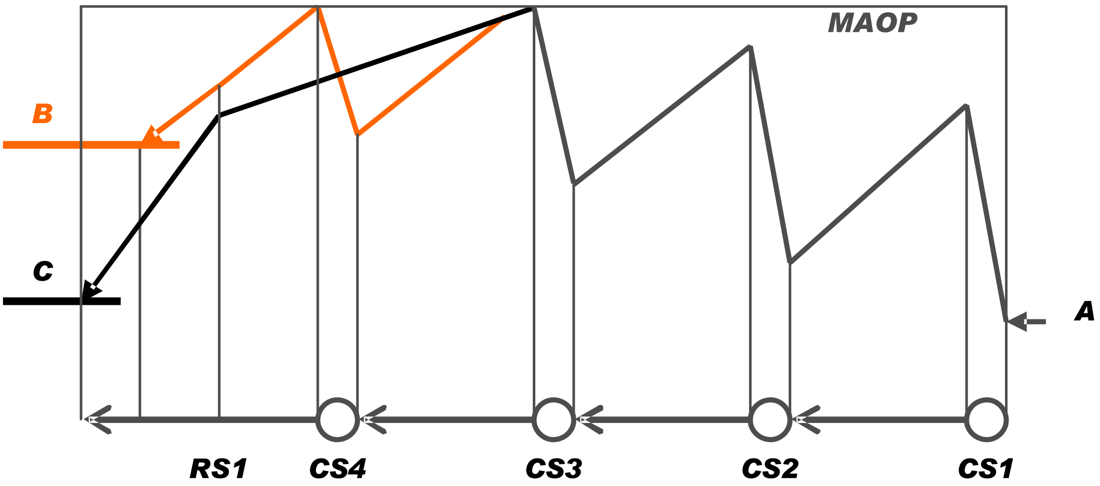


Fig. No.6. Course of pressures at hydraulic splitting of the transmission system

In case of insufficient gas volume in direction to C, a part of gas from direction B (with regard to higher pressure in this part of the system - Fig. No.6) is released by control valves at regulation station RS1 and at regulation station RS2 in direction to C. In this way it is possible to change operatively distribution of flows to the above stated directions, without changing the pipeline part configuration and also compressor machines part of the transmission system behind CS3. This design enables to operate the split system in the whole operational range.

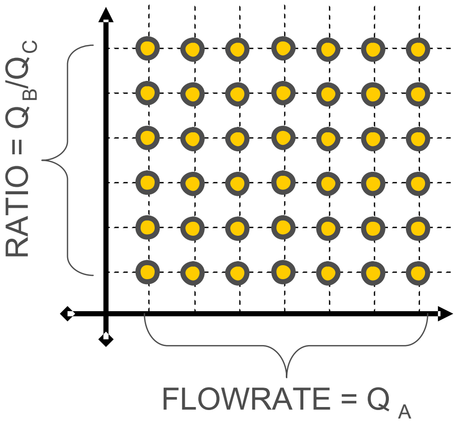


Fig. No.7. Calculation grid

Designing and optimizing the splitting system was carried out using the grid method (Fig. No.7). The calculation grid was determined based on the trend from previous years and the expected change of gas transmission in a relevant range of flowrates through point A and ratio of flows of both main outputs from the transmission system B and C. Simulations for both unified and split hydraulic mode were carried out for each individual grid point.

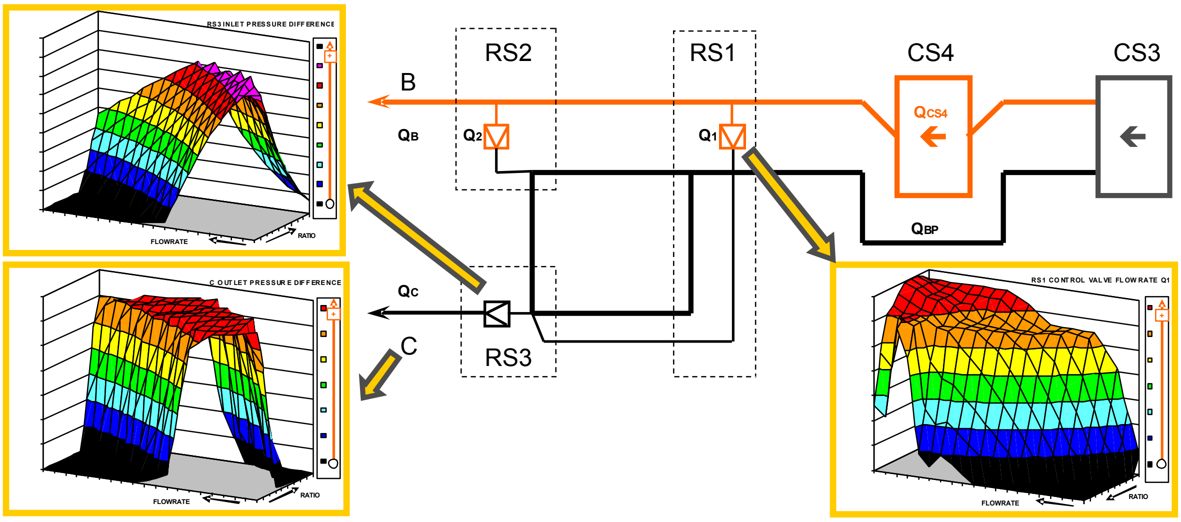


Fig. No.8. Utilization of the results from calculation grid

Thereafter all system parameters were determined in each individual grid point, namely configurations of compressor stations, pressures at their inputs and outputs, necessary compressor power, flow rates passed in control valves, operating points of used machines, etc. The calculation grid with results can be seen in Fig.No.8, where the corresponding flow through the transmission system (FLOWRATE) and flow ratios B/C (RATIO) are indicated.

Based on following analyses an optimal operation of the transmission system was recommended together with operating of relevant modes of compressor stations concurrently taking into account specific features of gas transmission in our conditions.

The following methodology was used for evaluating individual parameters used as a key system indicators of the operation of the transmission system. The values of the given parameter for an optimized system (hydraulically split) were subtracted from values of the corresponding parameter in individual points of the grid for the system before optimizing (unified regime). By that the calculation grid is obtained for difference of the given parameter in the corresponding extent of flowrates and flow ratios. Consequently, in this extent the function of the parameter difference was compiled depending on the flowrate through A and the flow ratio B / C. Graphs of the above stated functions can be seen in Fig. No.9.

On the basis of real operation of the transmission system, each day after certain period it is possible to determine the flow through inlet A and the flow ratio of the outlets B/C (Fig. No. 9, bottom). On the basis of the flowrate and the ratio it is possible to create picture of the day in the operational area - calculation grid. By this way it is possible to transform this day by means of determined function to the value of difference of the monitored parameter in such a way, as it is shown in Fig. No.9.

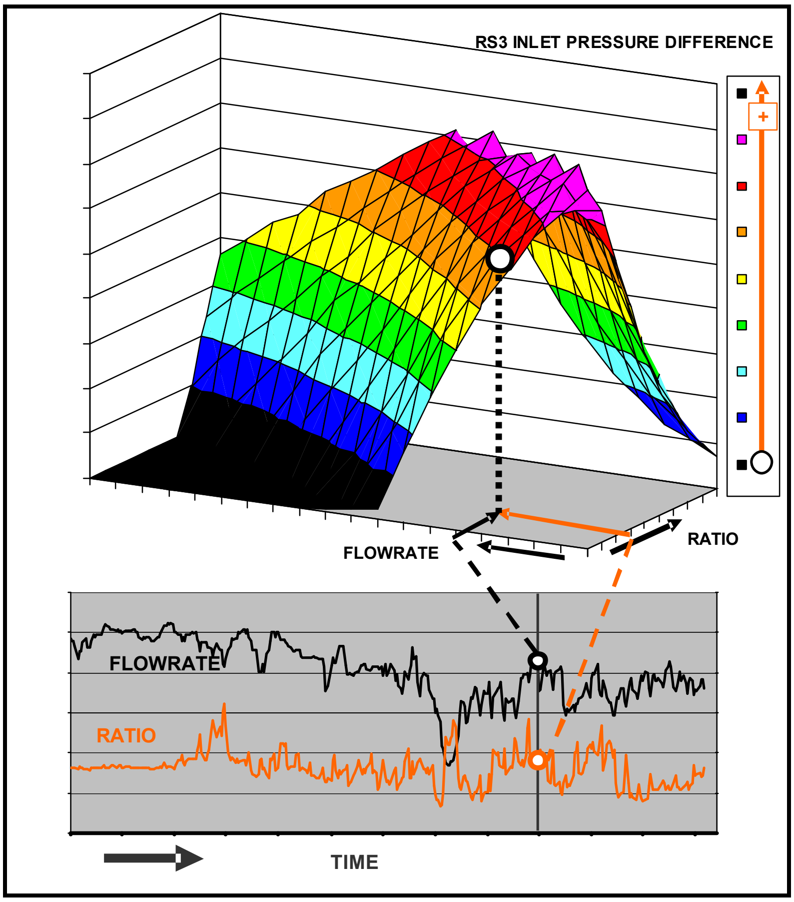


Fig. No.9. Method of assessment of differences on the basis of real operation

By stating the differences on the basis of the given function with utilization of the described methodology, the sensitivity analysis can be done in respect of the impact of the increasing or re-routing of the flow on differences of any parameter. Results achieved by this way are based on the real operation and, therefore, the assessment of the operation in the future, including the expected change in flows, stands on a strong fundament.

Project implementation into practice was based on the results and recommendations achieved in the theoretical/computational part. Since the split system was a “novelty” after almost 30-year-long operation of the transmission system, it was very important in the beginning of its live operation to combine correctly current practical experience of people involved in the transmission control together with new demands put on the system control after its splitting. It has to be mentioned that one of the important factors was to gain trust of people from practice in the results of simulation. However the trust was being acquired gradually at changes of this nature and in principle by continuous comparison of reality and our recommendations from calculations.

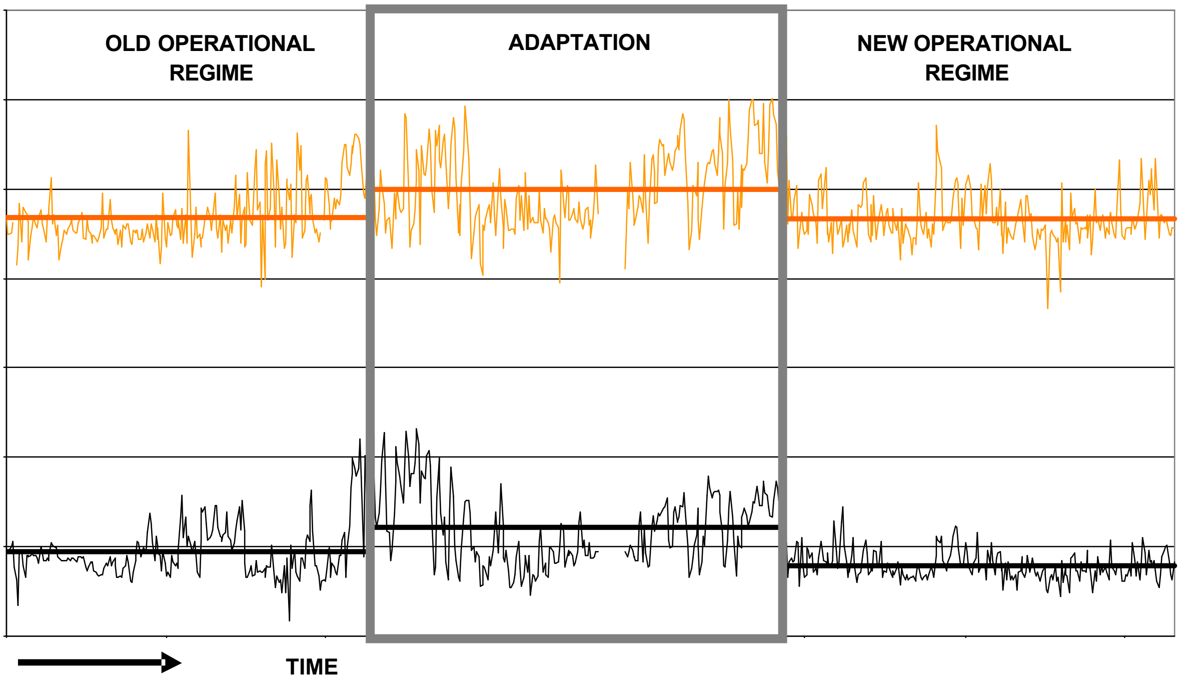


Fig. No.10. The pressure course of the points B and C during real operation of the split system

After taking into account operational specificities of the adaptation phase of real operation (Fig. No. 10) it was proceeded gradually with standard operation of split system, which at the present time has been successfully operated in the fourth year and it is considered to be a good tool for reaching the goals, for which it was designed.

4. Method of optimization of the compressor fleet

Taking into account the overall system optimization it was very important to start with optimization of the strategic pipeline infrastructure and to test in the practice the reliability of the results and the recommendations achieved in the computational part. Based on the experience from the operation of the optimized strategic pipeline infrastructure it was continuously proceeded with addressing the impact of Nord Stream on the required technical capacity and resulting compressor fleet.

For reaching the maximal required transmission capacity after Nord Stream startup the existing compressor units have sufficient power, even when it will be needed to carry out certain technological adjustments for reaching harmony with new emission limits which will come into force in 2016.

Before the optimization the compressor fleet consisted of the following general types of the compressor units technology:

- Technology with dry low emissions system [DLE] inline with new emission limits
- Technology with possibility of modifying to DLE [MDLE]
- Technology with ellectrically driven compressor units [ES]
- Obsolete technology with output power 6MW [6MW units]

Nearly 50% of the installed output is generated by 6MW units (Fig. No. 11) with a consequence, that pipeline yards of compressors stations are very complex with a large number of installed fittings. This increases the risk of natural gas leakage. The technology of 6MW units is comparatively obsolete, even though it is reliable, it contains some technologies, for example expansion starting system, which, due to operational reasons, ventilates remarkable amount of natural gas to atmosphere. Therefore the efforts of Eustream to reduce methane emissions are focused mainly on this technology.

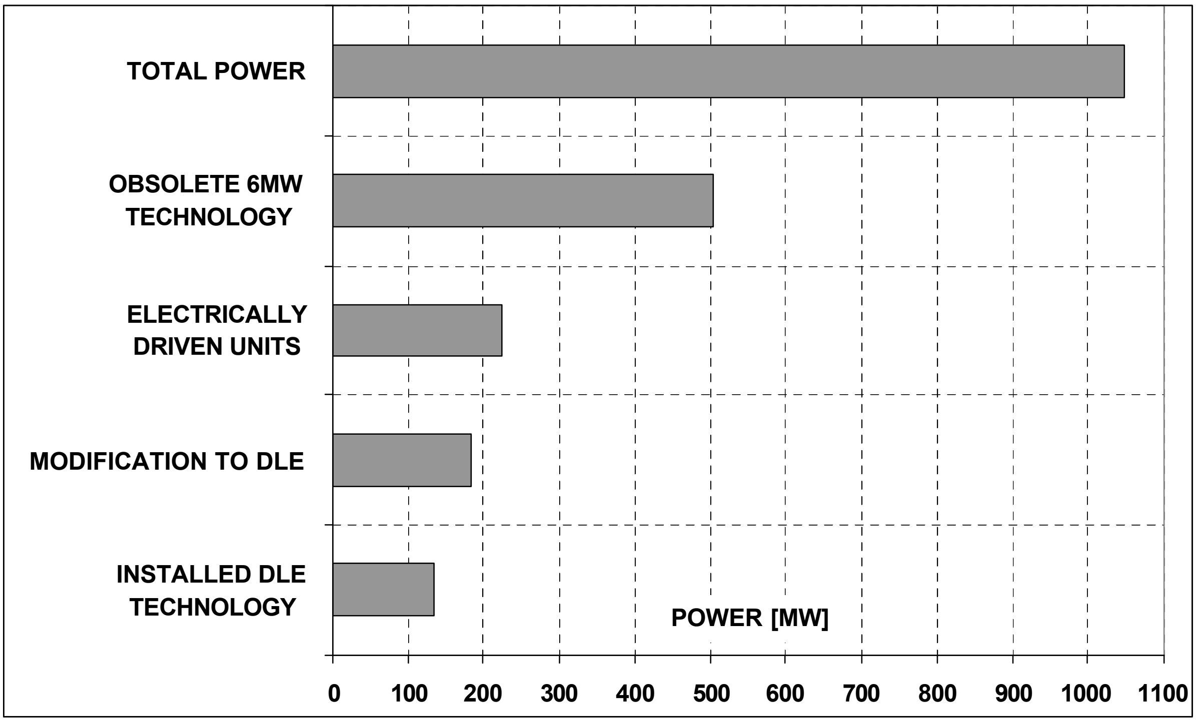


Fig. No.11. The total power distribution before optimization

Regarding the new legislation, the currently operated technology MDLE will fail to comply with the new emission limits proposed by the European Commission as of 2016 (75 vs. 370 mg/m^3 NOx). Concerning the 6MW units technology, these units will most probably not comply with the new emission limits proposed by the legislation of the Slovak Republic (150 vs. 300 mg/m^3 NOx). The total power influenced by the new emission limits is nearly 700 MW – see fig. No. 11.

Regarding the MDLE units, the project of replacement of gas generators with standard system of fuel consumption by DLE with low values of produced emissions was launched in 2010.

The 6MW units required to cover the target technical capacity have to be adapted to reach the new emission limits . This automatically raises the question, weather it is reasonable to invest in the obsolete 6MW technology. The alternative would be to shut down these units and install new big units with higher operational flexibility and lower emissions. This alternative has been thoroughly analyzed and has proved to be viable.

On the other hand the replacement of the 6MW units by the new units with the same output power of 6MW was proven as ineffective because of high investment per one megawatt of output power. The main recommendation of the optimization was to replace the required 6MW technology by new units with the output power of 23 – 33 MW.

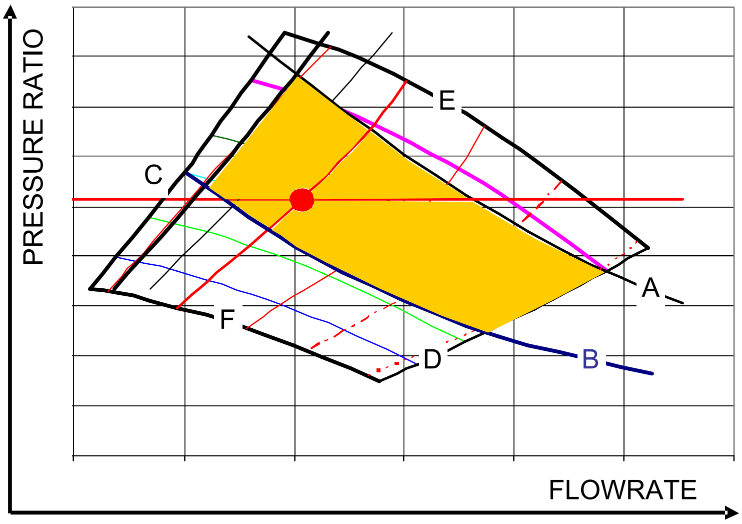


Fig. No.12. Real usable operational range of compressor unit

This result also puts emphasis on the parallel cooperation of big compressor units in the compressor station in connection with the DLE system operational range. When compared with the standard system, the DLE system has, in addition, also a limited effective area of operation which is usually guaranteed at the loads higher than 70% - it depends on the technology and manufacturer. This issue leads to narrowing the operational area of the compressor unit as shown in the Fig. No. 12.

The minimum power in connection with DLE adds a new restriction in the compressor performance map and the usable area of compressor is determined by the following lines:

- A - Maximum power at ambient temperature
- B - Minimum power based on DLE technology
- C - Surge line
- D - Choke line
- E - Maximum compressor speed
- F - Minimum compressor speed

Fig. No.13. Parallel cooperation of big compressor units in compressor station

The net usable area of a compressor has to be included into overall optimization process. The parallel cooperation of the compressor units in the compressor stations should be optimized to cover all expected operational regimes without any empty space – see figure No. 13. Any empty space represents an area where the compressor station is not able to cover the system requirements on the continuous basis.

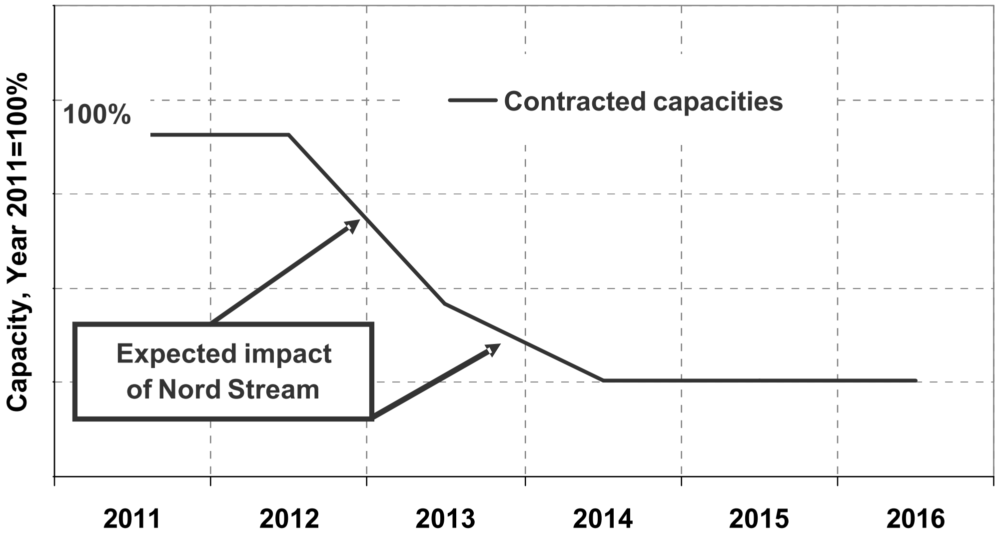


Fig. No.14. Capacity demand and the expected impact of Nord Stream

Based on the experience with the operation of the transmission system and taking into account the hydraulic analyses including the new restrictions, the reduction of the installed power at compressor stations is possible in the first phase under the conditions of new contracts (Fig. No.14).

The second phase of the power reduction is based on optimizing the compressor stations operation under the conditions of the optimized pipeline infrastructure. The main messages of the second phase are as follows:

- During the gas transmission in the pipeline network, energy supplied to gas in the form of compression work is fully used for overcoming pressure losses due to hydraulic resistances. From this point of view, especially the length losses in pipelines between the compressor stations are significant. The length losses depend on the flowrate (higher flowrate = higher losses) and the pressure (higher pressure = lower losses).
- The total power reduction is mainly determined by the required target capacity and level of the optimization. The rough principle of optimizing is to add as much compression work as possible at the beginning of the system (CS1) in order to increase pressure up to the maximum operational pressure of pipelines [MAOP] (Fig. No.15, yellow color). The high level of pressure at the beginning of the system reduces the pressure losses and resulting required power downstream – at the other compressor stations (Fig. No.15, yellow color vs. grey color).

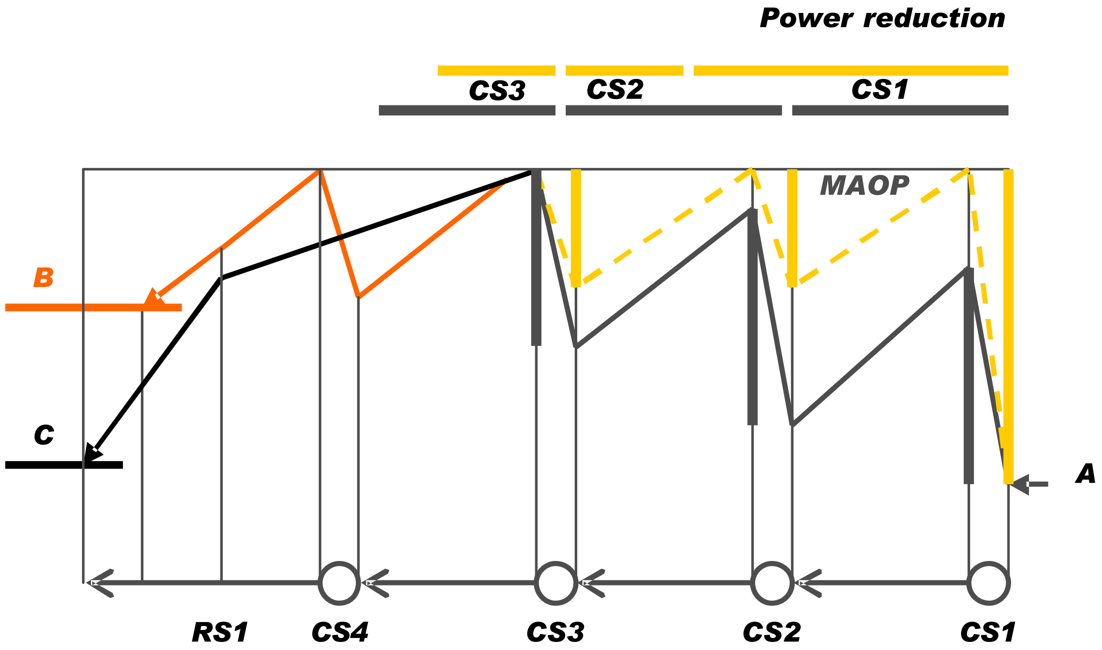


Fig. No.15. Main principle of second phase optimization

In order to enable high pressure at the outlet of the CS1 the high pressure ratio at this compressor station is necessary. The maximum pressure ratio before optimization was 1.39 and in order to reach the MAOP the pressure ratio higher than 1.5 is required.

In addition, before optimizing at low pressure ratios of CS01 the inlet pressure fluctuations had significant impact on the system operation. Due to that only in case of the high pressure ratio (1.5 = optimum after optimization) in the whole operational range of the CS1 the proposed power reduction was recommended at the other compressor station (Fig. No.15 and 16). The highest level of the power reduction is at the compressor station CS2.

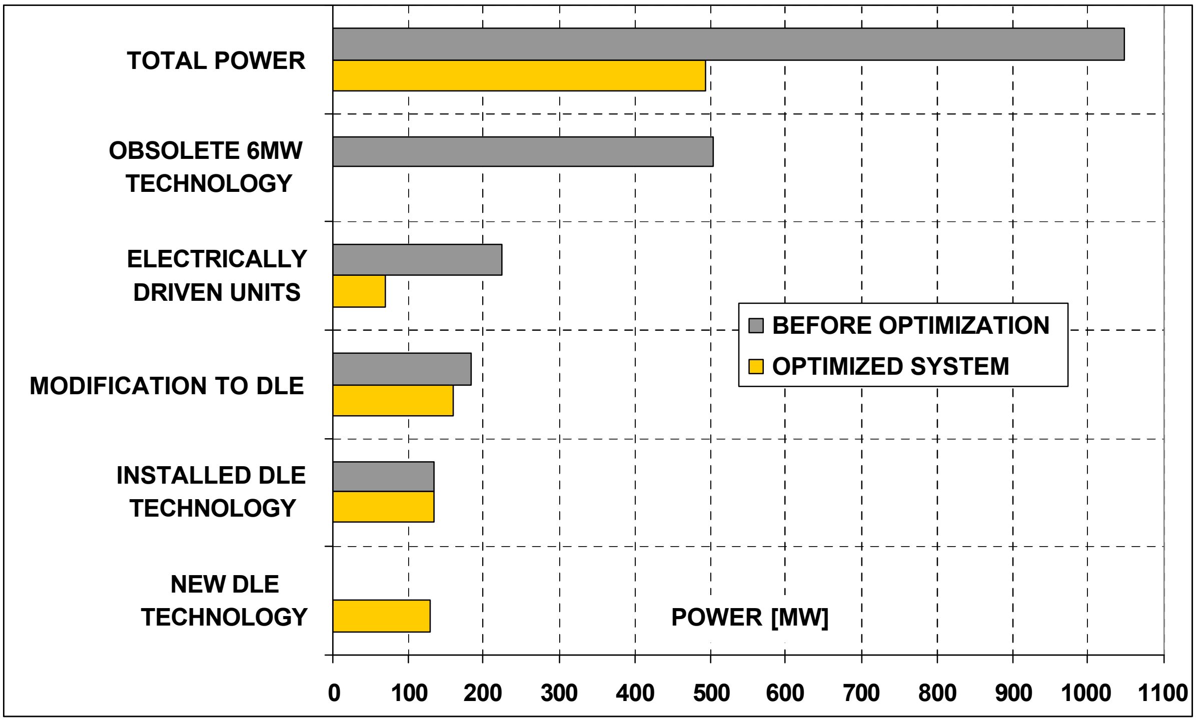


Fig. No.16. Expected power decreasing after optimization

The project of the pressure ratio increasing at CS1 represents the first measure and it was a starting point of all the following projects. The new design of the transmission system after optimization (Fig. No.16) will provide enough compressor power including backup in order to secure the required transmission capacity (Fig. No.14). In addition, the high pressure ratio of CS1 reduces the influence of the inlet pressure fluctuation on the whole transmission system operation. It results in a stable system operation behind CS1 without dynamic changes and thus increases safety, reliability and flexibility of gas transmission.

As it is shown in Fig. No.15, as a result of the CS1 pressure ratio increase the pressure ratio of the downstream compressor stations decreases. This also puts emphasis on the operational range of the compressor units at the downstream compressor stations in connection with the DLE system. In order to meet the new requirements the new units with tandem compressors (two compressor units on one shaft, Fig. No 17) are being installed at the station CS3. The project of new units at CS3 is strongly focusing the expected operation of the transmission system in the future and the aim of this project is:

- to replace obsolete 6MW units with high emissions by new fully automated turbo-compressor units with low emissions
- to broaden the CS3 operational range in both low as well as high compression ratio area
- to substitute the 6MW units operation at low pressure ratio
- to be in compliance with existing big compressor units with high pressure ratio

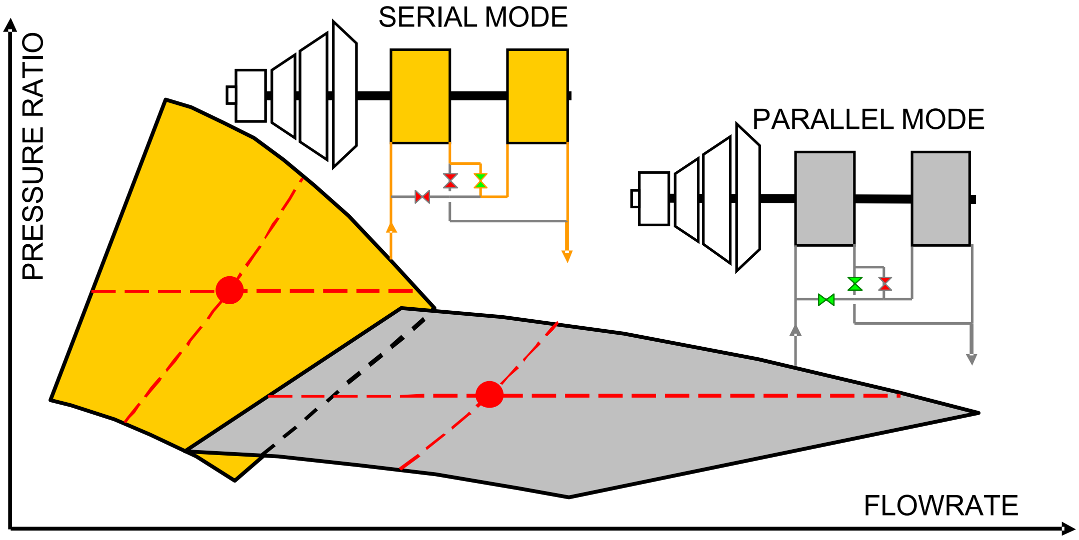


Fig. No.17. Wide operational range of the tandem compressors

5. Summary of results of the system optimization

The main driver of optimizing the gas transmission network in Slovakia was to address the impact of Nord Stream, as well as the impact of the new legislation on the emission limits. The achieved solution is a result of the comprehensive optimization, which consists of two key parts. In the first part the optimization of the pipeline infrastructure was performed with a target to utilize the full potential of the existing pipelines, i.e. all pipelines are utilized in the new operational regime. In the second part the impact of Nord Stream on the required technical capacity was a key driving force for the compressor fleet optimization.

Based on conducted hydraulic analyses and experience gained in operating the transmission system, the reduced power of the compressor fleet will be sufficient for the provision of gas transmission under the conditions of new contracts and optimized pipeline infrastructure. The expected total power reduction is approximately 50% of the current aggregated power. The maximum technical capacity of the system with reduced power will be higher than 75% of the current technical capacity. This capacity will provide sufficient reserve for potential increases in transmission in a medium term as well as long term perspective (Fig. No. 18, for example the present discussions concerning rehabilitation of the transmission system in Ukraine, or interconnections with Hungary and Poland).

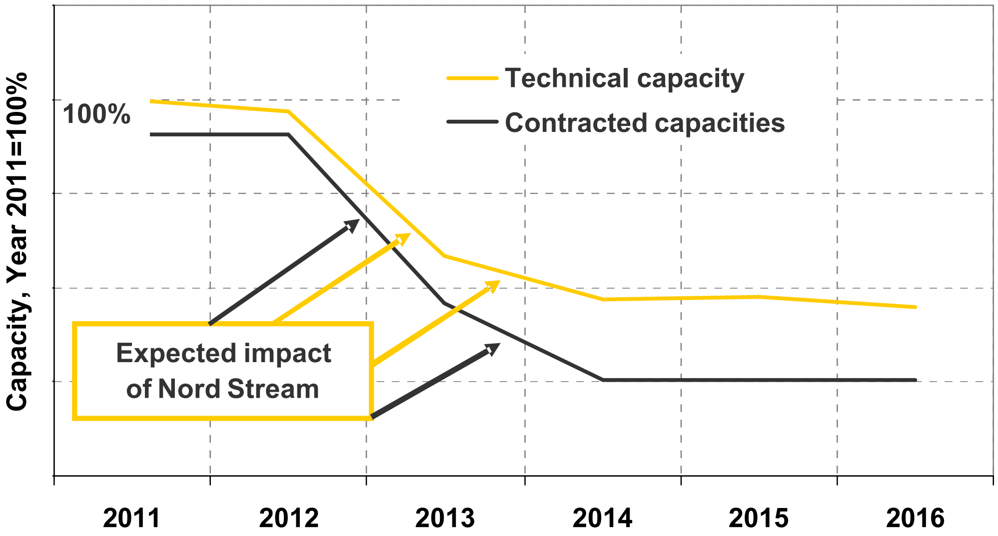


Fig. No.18. Capacity demand and the expected impact of Nord Stream

To reach the said target capacity, it is necessary to carry out certain technological adjustments to come into harmony with new emission limits, which come into force in 2016. Therefore, in 2010 the project was launched for replacing turbines (MDLE) with standard annular combustion by DLE system (Dry Low Emissions) with low values of produced emissions.

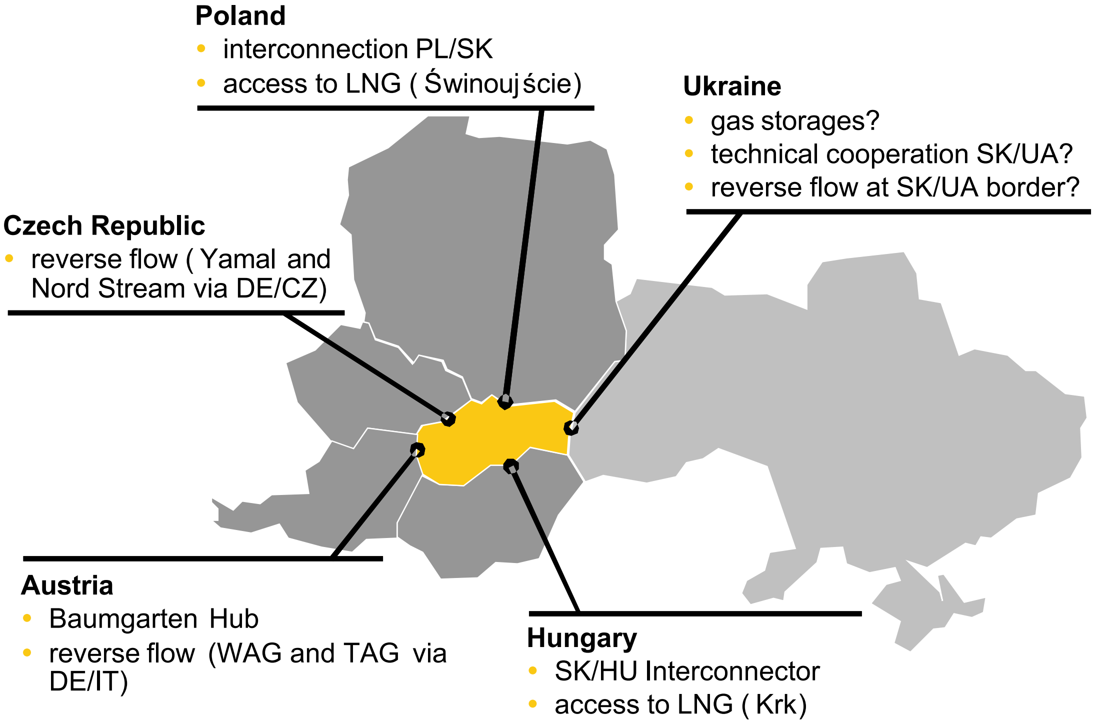
At the most important compressor station in Veľké Kapušany, new turbo-machines have been installed with high compression ratio and low values of emissions. These will replace a part of the old technology with low pressure ratio and high emissions. Furthermore, projects have been launched at existing compressors in the same station, which will deal with the replacement of internal hydraulic parts by new ones, possessing a high compression ratio. The increase in the compression ratio of the first compressor station over the whole extent of operation flows will make it possible to reach higher pressure at the start of the system. This will significantly contribute to the decrease in total demand on power downstream the transmission network. Lower demand on power allows a significant reduction of old compressor units, which consequently leads to lower emissions and thus also to a positive impact on our environment. Improvement of the ecological nature of operations will continue at the third compressor station, where new machines will be installed over the next few years with the aim of replacing the old compressor units with new technology that has a broad operational range and low emissions.

Due to the fact that the transmission potential of the pipeline infrastructure was fully maintained, there is high flexibility to increase the technical capacity to its previous level. In order to restore the current technical capacity the optimized investment plan was set up in consideration of the "Best Practice" solutions regarding the compressor technology. Of course, this increase has to be based on the demand regarding the transmission capacity in the future.

When looking to the future the flexibility of gas transmission infrastructure operation becomes a very important factor in relation to security of supply, gas crisis and reverse flow. From the very beginning of gas transmission through the territory of the Slovak Republic, the transmission system has been in continuous operation. This was applicable till January 2009 (gas crisis), which was a historical milestone in respect of the identification of “new” operational possibilities of the transmission network. The identification process started with reverse gas flow from the Czech Republic to Slovakia, and at present it solves full reverse gas flow with the possibility of interconnection to the transmission systems of surrounding countries. The aim is to provide transmission routes for multidirectional gas delivery (East-West / North-South) in case of future crisis modes and, simultaneously, in this way to open new possibilities for our business under normal conditions of transmission from East to West – see Fig. 19.

In order to increase the operational flexibility of Slovakia’s gas transmission infrastructure, two interconnector projects were considered as key elements:

- Slovakia – Hungary interconnector
- Slovakia – Poland interconnector.



Poland
- interconnection PL/SK
- access to LNG (Świnoujście)

Ukraine
- gas storages?
- technical cooperation SK/UA?
- reverse flow at SK/UA border?

Czech Republic
- reverse flow (Yamal and Nord Stream via DE/CZ)

Austria
- Baumgarten Hub
- reverse flow (WAG and TAG via DE/IT)

Hungary
- SK/HU Interconnector
- access to LNG (Krk)

Fig. No.19. Reverse flows of the Slovak transmission system and interconnectors

By establishing a link between the respective national transmission grids, the aim of the interconnectors is:

- to create a platform for a competitive, liquid internal gas market, while enabling the entry of new market players;
- to increase gas supply security in the respective countries and in the broader Central-South-East European region; and
- to ensure implementation of the North-South gas corridor.

Moreover, the interconnectors will provide the potential to connect with other projected trans-European gas transmission infrastructures (e.g. Nabucco, South Stream or with the LNG terminals in Poland and Croatia). In the event of a potential disruption in gas supply, the already existing Slovak transmission system together with interconnectors would be able to secure gas supply from possible gas sources to the rest of the Central-South-East European region. The bi-directional nature of the interconnectors is an important property of operational flexibility and it will be the main contribution to ensuring the security of supply in this part of Europe.

6. Conclusion

The new major gas infrastructure projects represent the driving force of existing transmission systems development. In order to be competitive to new parallel gas transmission routes, which are using “Best Practices” solutions, the optimization of existing routes is a must. This process will lead to implementation of “Best Practice” solutions also in the existing gas transmission infrastructure.

In the end, this global process of optimization could be an important step toward reducing the environmental footprint as well as developing several interconnector projects between gas transmission infrastructures.