Behaviour of transmission and distribution networks with big consumption, the stress test

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Abstract. Customers of gas transmission and distribution networks consume gas as they needed. Such consumptions vary continuously. It was found that within one day, in most of the cases, there are two major peaks. Because the gas is compressible, the load peaks can be covered from the network's linepack, with the condition that their dynamics are known and the network is prepared in advance, that is, "today" for "tomorrow". The paper presents the tools and the analysis of the natural gas networks and the limits of their safe operation. The paper also proposes a network stress test to verify the future behaviour of the network at high loads as well as to determine the necessary parameters for the next period of maintenance.

1. Introduction
EU legislation puts the consumers in the spotlight. Thus, the clients connected to the natural gas networks needs to receive this product in the parameters written in the contract. Because consumers use the gas depending on necessities, optimum management of the transmission and distribution network must be maid taking into consideration client satisfaction and safety condition fulfilment.

Natural gas volumes are traded by the providers and consumers on the gas market. These transactions are the base of the transport loads definition. Gas has to be delivered by the providers to each client respecting the quantities and qualities from the contract.

Preparing the transport schedule for tomorrow and/or the next days need to take into consideration the quantities required by the big consumers and the gas volumes needed by the small consumers. For this, the nominations are made based on consumption profiles.

Security of natural gas supply is affected by several factors: the amount of gas in the transmission network (linepack), the quantities of gas entering the system, the quantities of gas coming out of the system, the time of year, time of the day, imbalances introduced in the electrical system, problems with transport infrastructure etc.

In order to know the amount of gas needed for tomorrow forecasts algorithms are used. The importance of a good forecast on the natural gas market is given by the difference between nomination and allocation. If the forecasts are closer to real consumption then the cost of supply, gas stocks and cost penalties are diminished.
When the transport program for the next day [1] is prepared by the transmission system operator, the precision of the forecast is essential to balance the network, check if the nominated volumes can be delivered and refuse the capacity when certain values are exceeded.

In general, daily consumption values are forecasted for the small clients and loaded on the exit points from the network. Where this is a big problem arise because with daily average values for gas consumption a static simulation for the current day is made and the operational pressures are calculated.

With SCADA system entering the market a very big difference was observed between the calculated pressure with static simulation and real values from the gas network. The static simulation cannot reflect correctly the dynamic situations from the gas transmission or distribution network because the client’s consumption has hourly variations. This can only be simulated using defined hourly profiles.

In figure 1 a comparison between nomination obtained using a forecast with hourly profiles and real consumption is presented along with the corresponding errors [2].

![Comparison between nomination based on hourly profiles and real consumption](image1.png)

**Figure 1.** Comparison between nomination based on hourly profiles and real consumption [2].

In Figure 2 is presented the hourly variation of pressure due to flow rates used by a big consumer (a town). One can notice that the gas consumption has 2 consumption peaks. The first one determines a local pressure drop and simultaneously the Linepack decreasing. After that, the pressure is building again, but it drops very much after the second peak.

![Variation of pressure in the RMS area](image2.png)

**Figure 2.** Variation of pressure in the RMS area.
If the Measurement Regulation Station (MRS) supply pressure is reduced with only 1 bar (see figure 3) in the middle of the second gas consumption peak a blackout appears. To overcome this kind of problems the pressure must be increase in that point. This will also influence the pressure regime in the entire network. The final pressures must be determined based on dynamic simulations.

Figure 3. Variation of pressure in the RMS area - alimentation problem.

Form the above we can have a partial conclusion: Operating pressure in transmission and distribution gas network must be generated by dynamic simulations. The loads for each exit point from the network must be modelled with hourly consumption profiles.

From our experience we find out that if a daily load of the transport network is used a pressure regime will result. Using this regime in dynamic simulations blackouts appear in more than 80% of the cases. In order to obtain an optimum pressure regime, that will ensure a safety functioning of the equipment’s in the transport networks, dynamic simulations must be carried out. We named this "network stress test".

2. Model simulation
In Romania there are a lot of big consumers directly connected to the National Transmission System (NTS). They have a consumption of between 720,000 and 6,000,000 Nm³/day, but hourly consumption may vary depending on demand [3]. Superposition of such high hourly consumption can lead to a crisis or emergency situation that may culminate with the gas supply interruption in the area.

For a safe operation of a big consumer, gas network must be prepared to deliver gas under the most critical situation [4]. There result critical parameters that must be observed so that there may not occur crisis or emergency situations [5]. Close observance of these parameters lead to decisions on the system operation.

Given the size of the Romanian transport system and the implications of such decisions, simulations of real situations are used. For the data on which decisions are taken to be as accurate as possible, the numerical simulator that process them should be based on a correct and calibrated model of the transportation network [6].

The process of gas transport is continuous and in order to obtain a snapshot of the network parameters at any moment in time it is necessary to have a dynamic simulator [1], because the SCADA systems can offer just a limited number of parameters and the cost are very high.

The simulator can complete the picture of parameters based on the real data received from some points in the network. The simulator can return as results also parameters that cannot be measured, like line pack for pipes [7]. The simulator can present the dynamic in space and time of transport parameters (pressure, flow rate, temperature, composition, calorific value) distribution [8]. A sample of how this simulator looks like is presented in figure 4. One can see how the network looks, what
equipment are available, what parameter are used in the simulations and can be seen on graphs, how results can be presented and thematic colouring for parameters.

As one can see the simulator use different composition for all the entry points and can track this composition all over the system.

Output flows of the transmission system are established on the basis of daily nominations of gas volumes required by customers [9]. These flows are examined on the basis of consumer profiles for each output point, in order to see the level of solicitation [1, 4]. Without these checks, there is a risk that customers may use quantities of gas daily supplied from the NTS without paying them, as payment will be made on a monthly basis.
Consumer profiles for an exit point (measurement control station - MRS) are established taking into account the main consumption factor determined for the previous gas year to which a daily, variable correction is applied, a variable component with temperature [8] and a correction depending on the day of the week [1]. Consumption forecast for the next 3 days is adjusted based on the previous days’ consumption that define consumer behaviour specific to each client.

In the next figure the simulation network is presented. We have a complex transmission system with 12 suppliers, 2 customers (one big industrial consumer and a town), 4 compressor station, 3 regulators and 1 Measurement control Station - MRS.

The network has 3 major branches and a total of more than 800 km of pipes. The town is similar with Bucharest in the terms of gas consumption volumes, who has also 3 major delivery lines. Each of the 3 major branches has at least 150 km, so the travel time of the gas will be very important in simulations. All the supply nodes have different qualities of gas. We used gas composition until C6+. There are platforms with 90% C1 and others with just 70 %. The quality of the gas is tracked all over the network.

In the paper we present 2 simulations made for a summer gas day that means from 6:00 today until 6:00 tomorrow morning. The difference between this 2 is that one is with daily loads for the consumers (50 and 992 MMscfd) and the other one is with hourly profiled consumptions

The small clients’ (non-monitored) consumptions behaviour is analysed with a performant profiling software (Figure 6). The consumption profile is created based on daily consumption data, temperature, day of the week and season. This software is used to analyse the consumption behaviour of an area in order to create good nomination forecasts for the gas volumes needed.
In Romania and perhaps in many other South-Eastern European countries the introduction of Smart Metering involves high costs. Because of this there has been introduced an AMR automatic measuring system which is designed for large consumers classified under B4-B6 categories. As for the small gas consumers, classified under B1-B3 categories, in order to reduce costs, readings are performed once every three months.

3. Result analysis
For a daily (every 24 hours) balancing of the network, dynamic scenarios are carried out with an hour-long pace, as shown in Figure 2. The input data employed comprise the gas supplies in the network measured at Source, the gas exits at the large consumers, the initial linepack of the network and the operating manoeuvres specific to the simulated time span.

The gas volumes consumed by the B1-B3 small consumers are initially estimated based on both the consumption profiles, illustrated in Figure 3, and the customer's consumption factor. These values are grouped for the whole town in a single point of the network.

The increased accuracy of the forecasted nomination volumes leads to a minimization of penalties for gas companies. This accuracy increases if the forecast is based on variable consumption factor for each consumer. Once the transport system load (gas values at the entry and exit points) is defined, the scenario creation for tomorrow transport programme can be made.

3.1. The first scenario - with static loads
In the next figure is presented the starting state of the network as a pressure coloured map. The colouring is based on 4 colours: red - if \( p < 5 \) bar, yellow - if pressure is between 5 and 10 bar, green - if pressure is between 10 and 20 bar and bleu - if \( p > 20 \) bar. As one can see only the town is at lower pressure, because is a distribution network.

![Graphs and charts](image)

**Figure 6.** Profile use and gas volume nomination.
Figure 7. Pressure variation in the simulation network - hour 6.

Because the consumer loads are bigger than the supply the pressure in the system is dropping until the last hour, when the pressure graph looks like in the next picture.

Figure 8. Pressure variation in the simulation network - hour 5 next day.

For a better understanding in figures 9 and 10 are presented the pressure and flow rates variation at city Gates (MRS). The pressure has a 20 bar drop during this day, but still the system can function. This is a day when the nomination is very low compared with the allocation.
3.2. The second scenario - with dynamic loads

The consumption volumes used as loads for the entry and exit points from the network derived from the gas market. Each registry for each consumption point must be divided using the hourly profiles defined from historical data [5] in order to be used in dynamic simulations (Figure 11). The town profile is generated with 3 peaks due to the (30-70) % of gas volume consumed by the industry and small consumer. The Industrial consumer situation is common because of the daily program of the companies, i.e. from 6 to 18 hrs.

With these new loads, the simulation is made starting from the same starting state as before, thus means that the first hour pressure map will be similar with the one in Figure 7.

In the case of profiled consumption for the Town and Industrial consumer the simulation encounters a negative pressure at hour 21 (see the red part of the network from Figure 12), thus meaning a blackout in gas delivery to the clients.
In order to explain why the pressure has such a big drop let us analyse the profiled flow rates of the customers. In Figure 13 one can see the hourly gas flow rates for the Industrial consumer (values in kg/s) and the Town (values in MMscfd). The main problem occurs because of the high volume of gas consumed by the town in the afternoon. Form 17 hour to 23 the consumption is bigger than the average due to many home activities (cooking, washing, etc.).
Figure 13. Hourly gas flow rates for the Industrial consumer and the Town.

Because the gas entering the system is less than the exit gas the linepack is consumed. Even if the linepack is big, because of the long distances it cannot be used quickly, as is needed here. Thus, the pressure before the regulator of MRS is varying a lot, with a spike at 15 hours at 7.84 bar and going under 4 bar after hour 20. Before 21 the system is crushing as the pressure goes to 0, thus means no gas will be delivered.

In this simulation we keep even the negative pressure in order to show that after some hours, when the town consumption is reduced the system is going back to the initial state.

Figure 14. Simulated Hourly Pressure variation in the town RMS.
This simulation shows that the system is not prepared to cope with the hourly consumption for a day, so there should be taken measures in order to ensure a higher gas pressure in the system at the start-up time. Therefore, the energy security of the town, and by similitude the Bucharest area, depends very much on the way the gas transmission network is operated and on gas parameters.

In order to find the security conditions in which the town can work, there are made several changes in the network operation in order to have a running system, but the availabilities of some sources are insufficient to meet the demands and the pressure in the town MRS area is low.

Another measure that can be used is that the Industrial consumer to change his working hours to night shift when the town consumptions are reduced. In this way the hourly consumption are better balanced and the network can be functional for the entire day.

Figure 15. Simulated Hourly Composition variation in the town RMS - CO$_2$.

If the gas delivery assurance is the first priority and from that we obtain the pressure variation in the system, the second priority is the gas quality. Depending from which part of the network the gas is coming and the volume and composition of these Sources we can have big variation of quality at Town MRS. For exemplification purposes we present in Figure 15 the variation of CO$_2$ during a gas day. As the CO$_2$ is highly corrosive, the equipment’s must handle this big CO$_2$ composition. In this case, there is necessary to have a CO$_2$ removal unit.

4. Conclusion
To comply with safety requirements in the operation of the gas transport network, simulations to prepare next day’s schedule are dynamic simulations. In order to obtain the dynamics of the gas flows, alongside daily consumption profiles there are also used hourly consumption profiles specific to each exit point.

The influence of the hourly consumption profile can be seen when there are compared the situation in which power consumption is constant throughout the day and the situation in which consumption relates to a specific profile.

The problem of overcoming peak demands is a very important one to consider whenever establishing the transport program for the next day, in order to avoid any problems in ensuring the security of gas supply to consumers. Safe operation of the network is more difficult as these consumption peaks coincide in point of time.

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