Link between unaccounted for gas in transmission networks and flow-meters accuracy

F.Arpino[1], L.Canale[2], ML.Cassano[3], G.Cortellessa[1], M.Dell'Isola[1], G.Ficco[1], A.Tagliabue[3], F.Zuena[3]

[1]Università di Cassino e del Lazio Meridionale, Cassino, Italy
[1]Università Mercatorum, Roma, Italy
[3]SNAM Rete Gas Spa, San Donato Milanese, Italy
E-mail (corresponding author): g.ficco@unicas.it

Abstract

One of the main issues in natural gas transmission networks is represented by the so-called Unaccounted-for-Gas (UAG), that is the amount of gas related to the unavoidable measurement and estimation errors in the balancing equation of the network. In particular, accuracy of flow-rate measurement in transmission network pipelines is a very crucial issue due to the numerous related metrological criticalities. This paper is aimed at evaluating the influence of the flow-meter accuracy on UAG. To this aim, the rangeability limits of the flow-rate measuring device in delivery points characterized by large fluctuation of gas flows have been investigated, together with the effect of the drift of the instrument due to the absence of punctual periodic calibrations. From the analysis carried out, it was found that about 12% of the average daily flow rates measured at DSO measuring plants is below the minimum flow rate of the meter and that a significant correlation between monthly UAG and registered rangeability faults of flow-meters has been found.

1. Introduction

Unaccounted-for-Gas (UAG) is one of the main issues in Natural Gas (NG) transmission networks. UAG is the term in the balancing equation of a network which accounts the unavoidable measuring errors of the complex measuring chain devoted to the measurement of NG flows (which generally consists of a flow-meter, pressure and temperature sensors and a gas quality measuring device). Significant and tendentially positive/negative UAG values can be ascribed to the rise of systematic errors which do not always compensate each other. Unfortunately, such errors are not easy to detect and, in this regard, accuracy of flow-rate measurement in transmission network pipelines plays a very crucial role due to the numerous related metrological issues. Furthermore, the NG nature and composition in the EU transmission networks is expected to rapidly change in the next future [1-7]. As a In fact, recent politic scenarios are pushing the supplying from different sources (e.g. LNG from Qatar, Kenia, US, Australia) as well as to the energy transition policy incentivising the injection in networks of green fuels (e.g. biomethane, biogas and hydrogen). As a consequence, flow-rate measurement in networks will be trickier.

On the scientific hand, only few studies have been recently devoted to UAG in transmission networks. Botev and Johnson [8] demonstrated statistical control techniques on UAG can be effective in diagnosing of meter faults and when working with large faults detection times accurate estimates of the exact error location in the time domain can be obtained. In [9] the authors proposed a prediction model of UAG and validated it against experimental data. The measuring device accuracy [10] was also demonstrated to be a crucial issue, especially of those used for measuring the natural gas entering and leaving the network. Furthermore, significant correlations between monthly UAG and both the amount of natural gas transported and the external ambient temperature were found [11]. In the literature it is also recognized high variability of flow-rates can strongly affect measurement accuracy and, therefore, particular care must be devoted to the proper sizing of the measuring plants [12].

Measuring devices for volume/mass flow rate of gas flows typically show non-linear characteristic curve. This determines on one hand a limited rangeability of the instrument as a function of the physical measurement principle, on the other hand a decrease in metrological performance when the instrument works outside the measuring range for which the instrument is approved and calibrated. A further crucial issue is represented by the drift of the calibration curve of flow-meters over time.

In the natural gas sector calibrations are typically carried out using natural gas test medium and pressures close to the operating ones. However, in some cases tests in air and at atmospheric pressure conditions (i.e. much different form that in service) are carried out.

In [13] the effects of pressure and Reynolds number on the performance of a turbine gas meter have been investigated. At minimum Reynolds, the error of the turbine meter ranges between -0.4% (at 3 bar) to +0.8% (at atmospheric air) and this difference decreases as the Reynolds number increases (about within ±0.3%) when calibration in atmospheric air and with CO_2 at 3 and 10 bar are performed. An interesting finding is that errors at atmospheric air are underestimated at very low flow-rates (i.e. below Q_{min}), whereas at higher flow-rates, this effect can be considered limited within ±0.3%. Similar results have been obtained in [14] considering tests performed at air atmospheric conditions and natural gas at 3 and 50 bar. The error shift due to line pressure changes on turbine meters was found almost within ±1.0%, however some meters showed higher error shifts, especially above 0.20 Q_{max} (i.e. up to ±2.5%).

In this paper the authors analyse the effects of the flow-meter accuracy on UAG. To this aim, the flow-rates measured at Distribution System Operators (DSO) measuring plants in the Italian network have been investigated in respect to the rangeability of the flow-meters and aiming at assessing their capability to face flow-rate variations during transition periods (i.e. from winter to spring and from autumn to winter when civil gas consumption rapidly changes). First, the analysis of the flow-meter typologies installed in the network and of the related flow-rate regimes has been carried out. Finally, the effects of the drift and of the shift of the error curve of turbine flow-meters (which are the most spread in the network, especially in measuring plants of DSO) have been also presented and discussed.

2. Materials and Methods

2.1 Rangeability of the flow-meter

To ensure the nominal metrological performance declared by the manufacturer, each meter must operate within its own approved measuring range (i.e. above the minimum and below the maximum flow-rate). However, some plant configurations and operating conditions may lead (systematically or under particular operating conditions) to run the flow-meter outside this range, causing: i) an increase in measurement uncertainty; ii) the impossibility of carrying out the measurement during the duration of the overload (e.g. for Venturi meters); iii) the permanent loss of the functionality of the meter or its increased drift. The causes that most frequently determine these conditions are:

- daily and/or seasonal variability of withdrawals;
- variability of supply conditions (e.g. pressure);
- sizing of the meter with respect to the actual consumption profile;
- management of the measurement line (e.g. failure to change the "seasonal line").

To avoid anomalous situations, the set-up of the measurement system should therefore be adjusted by intervening on: i) the seasonal line change (winter/summer); ii) the measurement pressure variation; iii) the change of the network configuration (e.g. the closure of some plants in the presence of several entrances in the same DSO network). In particular, the seasonal line change should synchronize with the attenuation of the heating systems at the end of the winter season and with the activation of the systems at the beginning of the heating season. In reality, due to interventions planning problems and also in order to avoid breakages or malfunctions of the primary element, the DSO generally anticipates the winter change and/or postpones the summer one, making it more likely that, in the latter case, the meter will be run below the transitional flow-rate, and often even below the minimum one, even for long periods.

A sample of measurement plants of the Italian transmission network redelivery points was statistically analyzed in order to verify the possible correlation of the monthly UAG measured with the issues related to the use of the meter within the correct measurement range (i.e. adequate rangeability meter). For this purpose, the following were analysed:

- the number and punctuality of seasonal line changes in the DSO measuring plants;
- the trend of the average hourly flow rates measured before and after the seasonal line change in typical DSO measuring plants (large and small);
- the number of occurrences of hourly flow-rate measurements below the Q_{min} in industrial and DSO measuring plants.

With regard to the latter aspect, the authors also assessed the number of industrial and civil plants operated in the appropriate range of the instrument (i.e. between Q_{min} and Q_{max}) for less than 75% and 85% of the time for medium-small and large size (i.e. with nominal flow-rate Q_n below or above 30000 Sm^3/h), respectively. This latter represents a Key Performance Indicator (KPI) recently proposed by the National Authority (Arera) to tackle this issue.

2.2 Accuracy of turbine flow-meters

As well known, turbine meters are the most common on redelivery points of the national transmission network and in particular at DSO measuring plants. Turbine Meters are inferential flow meters measuring gas flow volumes indirectly through the measurement of gas velocity with a helical impeller placed in axis with respect to the flow (axial turbine) or a vane impeller arranged perpendicularly to flow (radial turbine). In fact, the gas rotates the rotor at an angular speed n which is proportional, through a calibration constant k, to its own speed and therefore to the flow rate Q, according to the following equation:

$$Q = k\,n \tag{1}$$

Ideally, the angular velocity of the turbine is directly proportional to the volumetric flow rate and shows a constant calibration factor k and flat error curve. However, both mechanical and fluid drag on the rotor affect the actual angular velocity, which is a function of the Reynolds number.

Turbine meters generally show: i) good rangeability (variable from 20:1 to 50:1); ii) transition flow rate generally variable from 0.20 Q_{max} to 0.10 Q_{max} for 20:1 and 50:1 rangeability values respectively; iii) typical accuracy within ±0.25% for gas flows; iv) drift over time within 0.1%/year, even if it depends on the volumes and average flow-rates delivered. Their main limit is the sensitivity to installation effects (in particular to swirl and pulsating flow rates). To this aim, manufacturers and technical standards suggest to provide a minimum length of straight pipes corresponding to 10 pipe diameters upstream and 5 downstream of a turbine meter.

3. Results and Discussion

3.1 Rangeability of the flow-meter

Aiming at assessing the extent of errors deriving from the non-optimal operating conditions of the flow-meter, a study was conducted on a sample of 218 DSO measurement lines during the month of May 2019 (when the seasonal change is typically carried out). The analysed sample is made up of volumetric turbine lines. From the analysis of the hourly flow-rates it has been observed that in the investigated sample, the measurements in non-optimal conditions (i.e. below 0.05 Q_{max}) are mainly concentrated during the night hours (i.e. from 11.00 pm to 05.00 am), as shown in Figure 1.

For a better understanding of this effect (i.e. how much the adjustment of the measuring range can influence the accuracy of the data), the effect of the line change on the sample of turbine meters in terms of average hourly flow rate trend before and after the line change was analysed in 84 out of 218 DSO plants, i.e. where the line change was carried out (see Figure 2).

The graph shows that before the line change the operation of flow-meters tended to be inconsistent with withdrawals as it was in average below the transition flow rate (i.e. 0.1 Q_{max}) and for long periods even lower than the minimum flow rate Q_{min}. After the line change, the upward translation of the measured hourly average flow rates is observed, highlighting a significant negative systematic error.

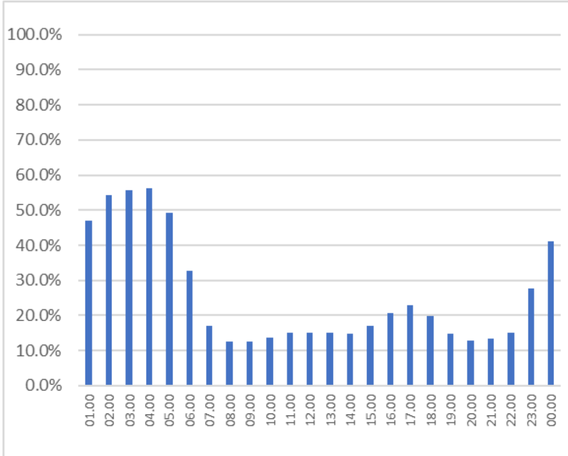

Figure 1: Hourly trend of the percentage of registered flow-rate below $\boldsymbol{Q_{min}}$ at DSO volumetric measuring plants in may-2019

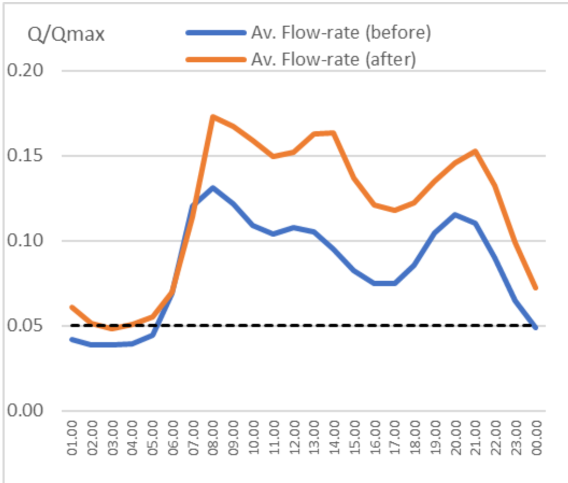

Figure 2: Hourly trend of the average flow-rate measured before and after the line change in 84 DSO measuring plants.

This effect is certainly more present on the numerous delivery points in the civil sector and less in the industrial sector, where the phenomenon is limited to periods of plant shutdown or production reduction. On the other hand, the phenomenon is certainly not present on the large measuring plant at entry points of the network. In this case, in fact, flow-meters are larger and generally more carefully designed. Furthermore, several measuring lines are available in parallel to better tackle the potential variations in flows. This leads to the underestimation of the consumption measured at exit points and therefore to the increase of UAG.

The authors also analysed the correlation of monthly UAG in the period 2018-2020 with the number of DSO plants operated below the KPI "rangeability" proposed by the Authority. From the analysis of Figure 3 it can be highlighted the correlation of the monthly UAG with the number of DSO plants below the KPI is evident, with a calculated correlation index equal to about 0.80.

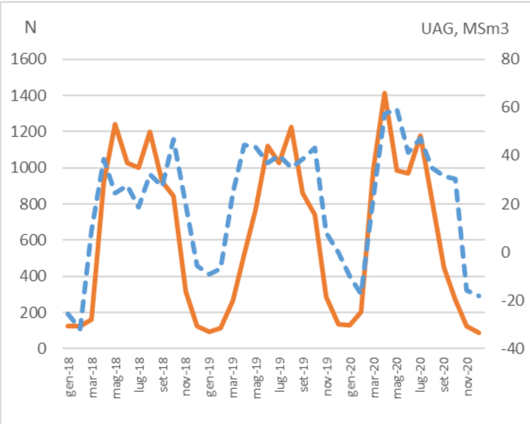

Figure 3: Number of DSO measuring plants below the KPI "rangeability" and monthly UAG

Finally, from the analysis of the typical error curves of turbine meters, it can be noticed that when the flow-rate values are lower than the minimum, the measurement error is higher and generally negative due to a greater influence of the associated friction and inertia forces to the motion of the rotor. Consequently, the use of turbine meters oversized with respect to the withdrawal profiles, can result in a negative error, and in a systematic underestimation of the volumes. Since these meters are mostly used at the exit points in the network, and especially in DSO measurement systems, the effect on the UAG is generally positive and not negligible.

3.2 Drift of the flow-meter

Figure 4 and 5 show the results of the subsequent calibrations carried out on two class 1 turbine flow-meters (TFM), with different size. In particular, the initial verification was carried out by the manufacturer with air at atmospheric pressure, while after a period of about 10 years the verification was carried out in the laboratory both with air at atmospheric pressure and with gas at line pressure.

From the analysis of the graph, in relation to the verification at atmospheric pressure, it is observed that: i) both flow-meters showed an average drift of the error in air at atmospheric pressure equal to about +0.6% and +0.4% for the large and the small flow-meter, respectively; ii) the weighted mean error (WME) calculated according to the OIML R137 of both flow-meters showed an error drift in air at atmospheric pressure equal to approximately +0.9% and +0.6% for the large and the small flow-meter, respectively; iii) the large flow-meter in the two verification points below Q_t (i.e. 0.2 Q_{max}) showed a significant negative drift (on average -0.4%) while the small flow-meter remained substantially stable. With regard to the verification with gas at high pressure, it can be pointed out that: i) up to Q_t for both flow-meters measurements with air at atmospheric pressure are underestimated in respect to those with gas at high pressure; ii) at higher flow rates the small flow-meter confirms the tendency to underestimate whereas the large one shows a reversal trend; iii) the WME shows a negative deviation (equal to -0.84%) for the large flow-meter and a positive deviation (equal to +1.14%) for the small one. In no case it was found that the maximum allowed error for subsequent verification provided by UNI 11600 standard was exceeded (which is equal to double the initial one, i.e. ±4% below Q_t and ±2% between Q_t and Q_{max}).

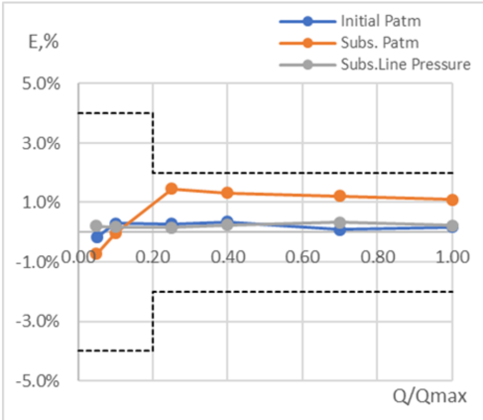

Figure 4: Drift of the error curve of a large turbine flow-meter.

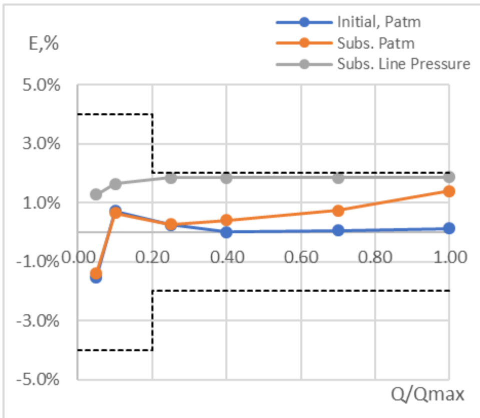

Figure 5: Drift of the error curve of a small turbine flow-meter.

4. Conclusions

In this paper, the analysis of the effect of the accuracy of flow-meters on UAG has been investigated in a twofold way by considering: i) the operative condition in respect to the rangeability of the meter; ii) the drift of the error curve of the meter over time. To this aim, the flow-rate trends measured at the measuring plants of the Italian natural gas transmission network were analysed, in particular considering the turbine meters at DSO measuring stations.

The results of the analyses show that:

- during transition periods (e.g. from winter to spring) at DSO measuring plants flow-rate measurements at non-optimal conditions (i.e. below the transition flow rate Q_t) are frequent and mainly concentrated during the night hours (i.e. from 11.00 pm to 05.00 am);
- before the line change, the operation of the meter tends to be inconsistent with withdrawals for long periods and with night withdrawals that tend to be lower than the minimum flow rate $Q_{min}$and often even zero. After the line change, the upward translation of the measured hourly average flow rates is observed, highlighting a significant negative systematic error and an increasing effect on UAG.
- an evident correlation between monthly UAG and the number of DSO flow-meters operated outside the correct rangeability was found;
- tests carried out on two turbine meters show that the errors in atmospheric air tend to be underestimated compared to those with gas under pressure, at least in the range up to Q_t.

Therefore, aimed at mitigating UAG in transmission networks, possible actions must necessarily guarantee the flow-meters devices to be operated in their approved measuring range (i.e. between Q_{min} and Q_{max}), avoiding flow-rate values below Q_{min} which leads to the underestimation of measured volumes. To this aim the following recommendations can be given: i) to install flow-meters with wide rangeability, especially in those application in which significant flow-rate changes are expected (i.e. in the measuring stations at DSO); ii) to punctually perform frequent periodic calibrations and seasonal flow-meter changes when a double measuring line is available; iii) to provide plant configurations capable to allow periodic in line checks with a calibrated control flow-meter.

References

[1] Gangoli Rao, A.; Van den Oudenalder, F.S.C.; Klein, S.A. Natural gas displacement by wind curtailment utilization in combined-cycle power plants. Energy 2019, 168, 477–491.

[2] Mazza, A.; Bompard, E.; Chicco, G. Applications of power to gas technologies in emerging electrical systems. Renew. Sustain. Energy Rev. 2018, 92, 794–806.

[3] Götz, M.; Lefebvre, J.; Mörs, F.; Koch, A.M.; Graf, F.; Bajohr, S.; Reimert, R.; Kolb, T.E. Renewable Power-to-Gas: A technological and economic review. Renew. Energy 2016, 85, 1371–1390.

[4] A. Perna, L. Moretti, G. Ficco, G. Spazzafumo, L. Canale, M. Dell'Isola, SNG Generation via Power to Gas Technology: Plant Design and Annual Performance Assessment, Appl. Sci. 2020, 10, 8443; doi:10.3390/app10238443

[5] Dell'Isola, M.; Ficco, G.; Moretti, L.; Jaworski, J.; Kułaga, P.; Kukulska–Zaja, E. Impact of Hydrogen Injection on Natural Gas Measurement. Energies 2021, 14, 8461. https://doi.org/10.3390/en14248461

[6] Stetsenko, A.A.; Nedzelsky, S.D.; Naumenko, V.A. The Effect of Hydrogen on the Physical Properties of Natural Gas and theMetrological Characteristics of Its Metering Systems. Metrol. Instrum. 2020, 6, 45–50.

[7] Farzaneh-Gord, M.; Mohseni-Gharyehsafa, B.; Toikka, A.; Zvereva, I. Sensitivity of Natural Gas Flow Measurement to AGA8 or GERG2008 Equation of State Utilization. J. Nat. Gas Sci. Eng. 2018, 57, 305–321.

[8] L. Botev, P. Johnson, Applications of statistical process control in the management of unaccounted for gas, J. Nat. Gas Sci. Eng. 76 (2020), 103194

[9] F.Arpino, M.Dell'Isola, G.Ficco, P.Vigo, "Unaccounted for gas in natural gas transmission networks: prediction model and analysis of the solutions" Journal of Natural Gas Science and Engineering 17C (2014), pp. 58-70

[10] G.Ficco, L.Celenza, M.Dell'Isola, P.Vigo, Uncertainty analysis of energy measurements in natural gas transmission networks, Flow Measurement and Instrumentation , Vol. 42 (2015), pp. 58-68

[11] Arpino F., Canale L., Cortellessa G., D'Alessio R., Dell'Isola M., Ficco G., Moretti L., Vigo P., Zuena F. Environmental Effect on Temperature Measurement in Natural Gas Network Balance. Journal of Physics: Conference Series 1868 (2021) 012028 IOP Publishing doi:10.1088/1742-6596/1868/1/012028

[12] Z. Gacek, J. Jaworski, Optimisation of measuring system construction in the context of high flow variability, Journal of Natural Gas Science and Engineering 81 (2020) 103447

[13] P.W. Tang Improving Turbine Meter Measurement by Alternate Fluid Calibration. CsHm March 2007 Presentation – Calgary

[14] R.Mascomani, J.Chandapillai. Quality Assurance and Calibration of High-Pressure Natural Gas Fiscal Meters. flotek.g Global Conference & Exhibition – 2017