Author: ing. Mooij, Ruud, Alliander, Arnhem, The Netherlands
Co-author(s): ir. Van Eekelen, Rosemarie, Alliander, Arnhem, The Netherlands, ir. Mans, Pieter, Alliander, Arnhem, The Netherlands, drs.ing. Robin Hagemans, Alliander, Arnhem, The Netherlands

A capacity management and monitoring system for optimising renewable energy and sustainability challenges in the gas distribution grids.

The gas distribution sector in The Netherlands is facing several sustainability challenges. The main challenges are reducing methane emissions, connecting a growing number of decentralised, renewable gas producers and changing customer needs from, for example, CNG-filling stations. Together with tight cost reduction targets these changing patterns form a huge challenge for the gas capacity management skills at Liander, a large gas distribution company in the Netherlands. From our perspective, this situation leads to pivotal new functions and innovative solutions in the gas distribution for the energy puzzle of the 21st century.

First of all, it will become a necessity to get detailed information on the gas flows. This is done by introducing a gas grid Capacity Management and Monitoring system (CMM-system) that contains near-real time gas balancing information on a 24/7 basis. The CMM-system functions as a day-to-day monitoring tool and provides essential information to optimize the (re)design of the gas distribution grid.

Several types of field measurements are needed for the CMM-system to work accurately. The measurements consists of flow, temperature and pressure sensors on all pressure levels of the gas distribution grid. The challenge lies in minimizing the number of measurement points needed to gain the required accuracy in the CMM-system, because the measurement points are costly.
To maximize the information obtained by a minimal number of measurements a simulation program called Model Predictive Control (MPC) is being developed. The MPC program simulates the near-real time behaviour of the gas in the distribution grid. Additionally, weather-dependent forecasts up to 3 days ahead can be simulated. The calculated values from the simulation are combined with the field measurements to verify the outcome.

Furthermore, the MPC model can be used for the development of consumer profiles by use of data obtained from Smart Metering. All data from the measurements and smart metering will be securely available online for grid operators using the CMM-system via a privately-owned CDMA wireless network.

The MPC program combined with the minimized number of measurement points will provide reliable information to enable an effective and efficient CMM-system for the gas distribution grid and enables maximum feed-in of renewable gasses, reducing methane emissions and facilitate more demanding gas consumers.

Papercode WP5-34

1 Introductions

Sustainable energy distribution is becoming increasingly important. The energy distribution systems facing challenges with facilitating renewable, decentralised energy production and reducing greenhouse gas emissions. More specifically, main challenges in the Dutch gas distribution grids are the injection and distribution of green gas and reducing methane emissions in transportation. Another development that has impact on the investment choices are emerging alternatives at the expense of the gas distribution grids like collective heat distribution. Aging of large parts of the gas grid will lead to a change in focus from construction to renovation and re-sizing issues. These factors, combined with a declining customer use of gas for heating, lead to an uncertain position and role of gas distribution in the future energy system. However, new emerging types of customers, for example natural gas filling stations, might lead to new gas demand for the gas distribution grids. These issues and developments will require an integrated management of the capacity and quality of gas and gas distribution systems.

The main developments in the operation of the gas distribution in the Netherlands and at Liander will be described in Chapter 2. Chapter 3 will elaborate on the simulation model and the main differences with other models. The building blocks for the measurements and simulations will be discussed in Chapter 4. The main conclusions and recommendations for the capacity management and monitoring system can be found in Chapter 5.

2 Developments in gas distribution The Netherlands

The use of natural gas in The Netherlands is widely spread. 98% of the households are connected to the national gas grid. As it seems, this is going to change in the near future. In contrary to the world gas reserves, the peak production of gas fields of The Netherlands has passed and sustainable alternatives to secure the energy supply become more urgent in the next decade. The use of fossil based alternatives like shale gas, coal (with or without capture and storage), and alike is under debate and the societal acceptance is declining. Furthermore, emission targets for new household are tightening and boosts the use of alternative heating sources like geothermal and industrial waste heath.

As a result, the use of natural gas is expected to decline and gradually shift from household heating to mainly industrial and business applications, mobility and supply of (small) collective energy systems. Also, the indirect gas usage for electricity production is increasingly forced in a back-up role to fill the shortfall intermittency of upcoming energy sources like wind and PV. The remaining gas will increasingly consist of sustainable produced gas like biogas, green gas, hydrogen and synthetic natural gas.

This shift in the role of gas in the Dutch energy system affects decision making at Liander, from strategic re-investment choices to the day-to-day practical operation of the network. Facing an ageing network, new and replacing assets must be judged on future requirements for network capacity and integrity in relation to the distribution and composition of new gasses.

2.1 Accurate information on gas flow in the distribution network

According to Liander, who distributes gas between pressure levels from 0.03 to 8 bar, a part of the answer to these trends lies in smarter, digital energy networks. Distribution will become more complex, hence it requires a higher level of control over the distribution of the gas.

In recent years Liander has started to develop a simulation model based on dynamic behavior of the gas network. One of the most important differences of the new model in comparison to existing network calculation models are its dynamic and predicting abilities by design. In addition, the risks in the network can be displayed in direct relation to the current status of the gas demand, weather conditions and planned interruptions.

Forecasting the behavior of the gas in a distribution grid is a rather practical challenge. Apart from the need for outstanding asset data quality, daily planned and unplanned interruptions must be taken into account and a complete set of all gas consumer profiles are needed. During the earlier development of the model, it became clear that dedicated and strategically placed sensors in the network are essential. The measurements are going to be used to verify the simulated outcomes and improve the accuracy of the assumptions in the model.

2.2 The 'digitalizing gas networks' program at Liander

Advanced simulation and modelling is needed to gain insight and control over the gas flows in the distribution networks. As a consequence, development of these models ask for more dedicated measurements of network performance and gas quality. The program that is currently being executed at Liander to achieve this higher level of operation is called 'digitalizing gas networks'. The beneficial goals of using simulation and forecasting models are numerous:

- Optimizing network investment in replacing ageing assets like pressure stations and gas pipes;
- better facilitate feed-in and distribution of de-centrally produced green gas, even when more producers are connected to the same grid and supply and demand is out of balance;
- higher standards in decision support and operational network control;
- increased transparency in gas losses and possible congestion management.

In short, 'digitalizing gas networks' program combines two major fields of expertise: modelling gas flows in a predictive way and the placement of strategically chosen measurements in de gas distribution grid. As the 'digitalizing gas networks' program advances, a third competence will be the control over the gas flows and quality of distribution.

2.3 Model predictive control

With the increasing availability of real-time, sufficient and validated data it becomes possible to instantaneous simulate and predict gas flow in the distribution grid. The method of modelling only takes en limited number of field measurements to generate presentable information from a large amount of data. This so called model predictive control (MPC) consists of a computational core that in an efficient way calculates the present state of the gas in the network continuously. For that, it uses input data like network characteristics, process values of pressure reduction stations and temporarily interruptions as a result of planned work. Another important input factor is the prognostic gas demand that is extracted from variable external input parameters like temperature, wind speed and direction, and gas usage from metered (large) consumers. The results are presented geographical and in graphs and contain information about pressure, flow and gas composition for a chosen specific location in de gas distribution network. De schematic design of the MPC is given in figure 2-1.

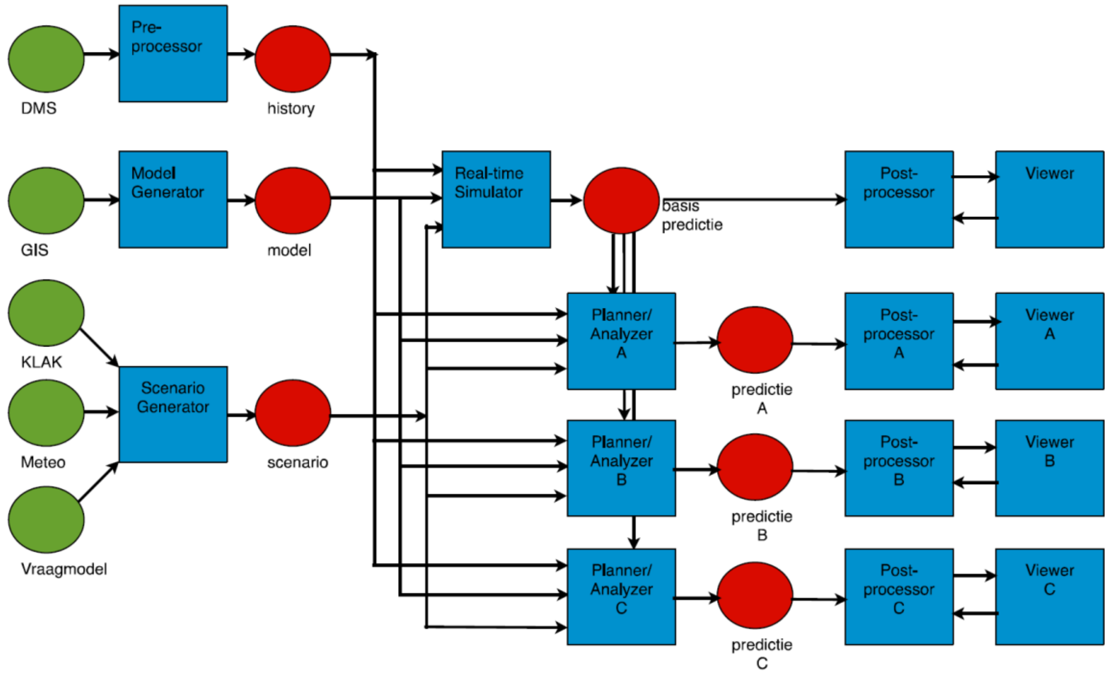

Figure 2-1 Schematic presentation of the MPC (source: Alliander DC demonstrator/simulator Global technical design, TNO, 21 May 2012.)

From this basic simulation scheme, different independent applications can be build. For now, two are being developed for different operational areas: one for use in the work planning process and another as asset management decision tool.

2.3.1 The work planning application

The work planning application is to be used as a decision support tool in daily network operation. It gives the operator in the control room specific information about the consequences of planned work given the actual and predicted network conditions for the next 48 hours. The work planning application as part of the MPC simulator can be used to calculate the present en near-future condition of (an entire part of) the distribution network. But it is also useable for calculating the effects of specific last minute maintenance activities, like the reparation of a reported gas leakage. The actual conditions of the network like weather dependent gas demand or other planned interruptions are automatically taken into account. This way, funded decisions can be made on the execution of planned or unplanned work. Continuity of gas distribution is better guaranteed.

2.3.2 The asset management application

The design and associated risks of the gas distribution grid is traditionally aimed at sufficient transport capacity and redundancy under extreme winter conditions. For The Netherlands, this means that all consumers connected to the distribution grids are contractually secured for sufficient gas supply up to minus twelve degree Celsius or the maximum of their meter capacity. This single design condition arose from the period that natural gas from a uniform quality source (Slochteren) is transported one way: through the national grid into the distribution grid and finally to the end consumer. Architectural design of gas distribution grids at Liander Asset Management is gradually shifting from that paradigm. Instead of growing demand and expanding capacity the design focuses more and more on utilizing ageing assets in a new way and adept to decreasing gas consumption in order to avoid the risk of stranded assets in the future.

In addition to the market and costumer developments mentioned earlier, this leads to different ways of distributing gas and hence to changing risks and risk evaluations. This alteration of risk assessments asks for different judgments and critical indicators regarding network design. In the designing and planning process of Liander Asset Management this is already being anticipated on, despite the lack of adequate decision software.

The asset management application uses the MPC to perform Monte-Carlo simulations over a chosen period of time to indicate the weak spots in the network and to determine their probability of a failure which means delivery interruptions or off-spec gas quality. The main goal of the application is to quantify the quality of the network in its natural state and calculate the robustness by determining the effect of interruptions (leak, false closure, deviate gas quality) and planned adjustments of a (selection of) asset(s). The outcomes does not only calculate this under the extreme winter conditions, but under all practical anticipated circumstances. The risk-based analysis as part of the application is being performed over an entire year of reference. This is done to provide insight in the consequences of events under all weather conditions, as well in summer as in winter. The asset management application uses the following input records:

- Reference datasets of external parameters like temperature, wind factor and transported gas volumes;
- failure models containing the historically determined effects of events;
- statistical models containing probability distribution of occurrence of events, depending on the cause of the event, the corresponding asset type and external conditions.

The interpretation of the results is done by a representation of pre-determined critical indicators. These indicators match the foreseen developments as stated above and relate to 1) the quality of the network, 2) the risk of interruptions, 3) limitations of green gas feed-in and 4) the risk of distributing off-limit gas.

2.4 Digital gas distribution: strategically placed measurement points

The physical properties that are directly measured in the distribution grid are gas flow (F), temperature (T) and pressure (P). The composition of the gas is measured only at the entry points. The challenge of placing the PFT sensors lays in a minimal but sufficient number of measurement points placed at suitable locations.

Before rolling out the first measurement points, a test phase has been conducted aimed at selecting the right equipment and experimenting with installing the sensors. Also, a set of learning objectives have been set for the first roll out phase. These objectives are aimed at the technical feasibility of installation at existing stations and pipelines, the reliability and accuracy of the measurements and data-communication, and finally, using the outcome values for monitoring activities and model validation. Apart from the technical lessons, Liander wants to vouch the economics of digitalizing the gas distribution network and the potential realization of the set objectives.

The first phase is aimed at optimizing and validating the basic assumptions of the simulation model. The placement of the PFT-sensors are initially based on outcomes from the first prototype of the MPC. De measurements feed the model with real data from a distinct part of the network. In this area it is expected that the learning objectives can be clearly determined with a limited budget for the measurements (approximately 14 locations). The first next step is realizing the installation of the sensors in the high pressure part of the selected network (1 to 4 bar(o)) before the end of 2014. After that, two other area will be selected with respect to the following specific objectives (table 2-1):

Areas	Objective	Explanation	Subjects
1	*Validation and verification of measurement point based on the MPC - simulation and network design with optimal use of measurement points.*	*In addition to verification also gain insight in potential realization of objectives with respect to monitoring and optimal use of the network*	*Monitoring* *Transparency* *Optimisation*
2	*Insight in effects of green gas feed-in on distribution and flows in the particular network. Validate ways of improving green gas facilities.*	*Gain insight in the dynamic behaviour of gas flow in a network where gas demand is known and where there is a continuous green gas feed-in.*	*Green gas* *Transparency* *Monitoring*
3	*Insight in optimal use of the high pressure network for dynamic pressure management. Optimisation of network design.*	*As a result of dynamic pressure management the flow of the gas changes. Comprehending these effects clarifies the optimisation puzzle.*	*Transparency* *Monitoring and Control* *Optimisation*

Table 2-1. Objectives of specific measurement testing areas.

3 Building blocks of the 'digitalizing gas network' program

The execution of the digitalizing gas network program is divided in several building blocks, which are generally discussed in relation in this chapter.

3.1 The MPC model

The MPC model mentioned earlier uses different input sources that can be categorized as follows:

1. DMS – Dynamic Management system with, among others, real-time process measurements (actual and historical values) like inlet and outlet pressure and other operational settings from regulating pressure stations;
2. GIS- a Geographical Information System containing the spatial information of the network;
3. Maintenance and repair data. Register of historical information concerning (planned) maintenance and (unplanned) interruptions;
4. Meteo – Database with local historical and forecast weather data;
5. User Demand – A database with gas usage per connection which, together with typical user profiles, determine the probable (maximum) gas demand at any given situation statistically.
6. Supply – Data regarding supply of gas by Gasunie Transport Services (GTS, the national TSO) and green gas producers

A scenario generator determines the outcome from this set of input variables as a function of time up to the prediction horizon. (Source: DC demonstrator/simulator Global technical design, TNO, 21 May 2012).

3.2 P, F and T measurements

The measurement points of pressure (P), Flow (F) and Temperature (T) are placed at reachable locations, where sensors and equipment's are easily accessible. The most practical location for pressure and flow sensors are above ground in a pressure regulating station. Despite this, it still can be necessary to have Flow sensors in the pipelines underground. The sensor placement requirements at selected stations during the first phase are specifically determined as follows:

1. Measuring the pressure at two points per station: the inlet and outlet;
2. A network with sufficient gas demand
3. Sufficient variation in Flow, preferably during one day. This enables research of the influence of short term dynamics and behavior of low velocity gas flows.

The requirements for each selected station leads to at least one Flow and Temperature sensor and two or more Pressure sensors, depending on the size of the installation. One of the requirements is the normal availability in the market.

The strategic selection of stations and locations in the network to place the sensors are primarily determined by the outcome of the MPC program. With this, the number and location are chosen with the aim of reducing the uncertainty in the model to the desired level with as few measurement points as possible.

For the size of the network under research at phase one, 14 measurement locations will be placed at the size of a network with approximately 8000 connections. For the whole of the distribution network at Liander, with 2,3 million connections, it is expected that 600 to 1000 measurement locations are needed to verify and validate the model for the entire network.

3.3 Telecommunications through the CDMA network

Liander owns a wireless communication network in the 450 MHz-band (CDMA). This band offers a suitable compromise between coverage and bandwidth for smart grids (e.g. the strategic measurement points) and smart metering appliances. The CMDA network works at low frequency, which has the advantage of lesser transmitter locations. For Liander, heavy technical performance is not the most essential requirement for the use of telecommunications to process measurement data in the gas distribution grid. In contrast, these are adequate safety and security, the costs of data processing, (wireless) coverage and stable performance.

3.4 Data communication and governance

The function of data communication is divided in two building blocks: The 'real time metering chain' and the 'context database'. These building blocks are connected to be able to deliver relevant measurement data to the MPC program.

The real time metering chain facilitates and secures the sensor data communication between the field measurement location and the central SCADA system (Supervision, Control And Data Acquisition) on a reducible way. An integrated part of the real time metering chain are security, measurement and data transport protocols, configuration of the chain and 'scanning' of measurement points.

The 'Context database' collects the measuring data in the form of time series (dynamic data) directly from the SCADA system and combines the data from the measurements to relevant Context data. An example of Context data is the predetermined static data. With this, a topological (point in the distribution grid) of geographical key will be used as a unambiguously trace data source. The key is paired with the dynamic time series and relevant static asset data like type of the component, type and range of the measurement, et cetera.

Liander has successful experience with in-memory technology for several gas and electric related business appliances, mainly in the domain of strategic assets. The main consideration for using this are costs versus business value of having rapidly available information. In-memory solutions are build as an integrated function of a calculation model and a context database.

Finally, Liander has chosen to focus on configuration standards for measurements to be able to remotely correct potential errors or make adjustments to measurement settings. This results in cost reduction during maintenance, because this can be done from distance and a better governance of static data quality of real time measurements. An example of such a standard is called the HART protocol. This protocol is a proven technology for standard configuration protocol and is widely used within the oil & gas industry. Liander applies the HART protocol in the 'digitalizing gas network' program.

4 To conclude

With the described developments ahead, reliable information becomes available for Liander to gain necessary insight in the gas flows with a minimum number of relatively expensive measurement points. The preliminary results with the MPC model are positive and the first run of simulations have been conducted. To verify the results, the first strategic measurement point are in place. The experience thus far give confidence in the ongoing work to be implemented successfully.

With the combination of the MPC model, user data and strategic measurement points, Liander is able to develop a reliable and accurate real-time simulation of the gas behavior in het distribution grid.

The necessary knowledge of various fields of expertise makes extensive cooperation essential for success. The contribution of broadly experienced and well qualified project members are pivotal for realization of the ambitious but indispensable goals set by Liander.

Model based measurements cycle