THEORETICAL CONSIDERATION OF LARGE DYNAMIC GAS DISTRIBUTION SYSTEMS, BY USING SIGNIFICANT COEFFICIENTS TO EVALUATE THE ENERGY EFFICIENY

Rene Schimon[1], Andreas Werner[1], Thibault Henrion[1], Markus Haider[1]

[1]Vienna University of Technology, Institute of Energy Systems and Thermodynamics
1060 Vienna, Getreidemarkt 9, Austria

rene.schimon@tuwien.ac.at(Rene Schimon)

Abstract

In times of heavily increasing energy costs, companies more and more try to find further cost reducing provisions. Large gas distribution systems, like those in integrated iron an steel works, have losses caused by different physical behavior. The physical contexts in large systems are complex. This makes it complicated to find causal relationships between cause and effect. To visualize those causal behaviors, the gas distribution system of a 5 mil. tonnes of steel producing integrated iron and steel work was numerically modeled. Therefore APROS, a simulation tool for one dimensional dynamic simulation of different gases, steam or water-steam media, was used. The blast furnace gas distribution was modeled and evaluated. With the model, different analyses in terms of controlling, disturbance and changing net configurations were realized. For easier comparison, it becomes more and more important to have an objective method in order to quantify the efficiency of different network configurations . Therefore two coefficients have been developed which make it possible to compare different configurations of networks in terms of efficiency. Furthermore the developed coefficients were applied to the dynamic model, to show how numerical simulation can be used to develop optimization methods for a later implementation into a real plant.

Keywords: Apros, integrated steel works, gas distribution system, minimizing losses

Presenting Author's Biography

Rene Schimon was born in Salzburg in 1978. He visited a technical school with focus on mechanical engineering. After one year working for a German car manufacturer in Regensburg (Germany) he started to study mechanical engineering at the Vienna University of Technology, with focus on biomechanical engineering. After finishing his study he starts a PhD project at the Institute of Energy Systems and Thermodynamics. At the University he engages in one- and two-phase flow in distribution systems, like in steam boiler or gas distribution systems of iron and steel works.

1 Introduction

APROS is a simulation tool which is focused on dynamic simulation of thermal and nuclear power plants. For simulating exhaust gas systems, different gas compositions can be generated. In integrated iron and steel works a huge amount of blast furnace gas accrues. The gas is mainly used in power plants for generating electrical power or district heating. Other applications are furnaces or finishing lines. The amount of produced gas is about some hundred of kilogram per second. For distributing the gas to the different plants, a widely ramified pipe network is used. Caused by the transient behavior of the sources and sinks, the pressure shows a very dynamic behavior. This leads to flare and pressure losses. The main question is which losses belong conditionally to the system and which losses can be avoided.

2 Model

The model of the gas distribution system covers all main pipelines with diameters form 1 m up to 3 m. All important valves, expansion joints, bends, flaps, venturi nozzle, compressors or other internals have been considered. Flare valves, flaps or other controlled valves are described, using their own characteristic curves [1]. All necessary control parameters and control loops have been implemented. A further parameter is the driving time of each valve or flap, which also was considered. The compressor model includes the characteristic curve of the real unit. The model consists of over 300 flow modules, 100 main control modules and few hundred additional modules for post processing, and visualizing of the results. For the introduced model, thermal losses have been neglected, because the temperature stays constant in average.

One goal of the the model was to have the possibility to make different case studies with only one model. Boundary conditions, control concepts, set points, valve positions etc. can easily be changed or switched (on/off). Also different disturbances can easily be switched on or off. Fig.1 shows an example for the implementation of a pressure control for a certain part of the network, which is described in chapter 3.1. For the interaction between flap A and B, different control concepts were compared. The best two concepts, in terms of pressure equality and supply guarantee, were implemented in that way, that it can be easily switched between concept A and B, by setting a binary signal true or false. **SP** marks set points to parametrize the model. Concept A uses a parallel flap manipulation; therefore an offset can additionally be given.
In the control example, a possible disturbance might be the breakdown of one of the flaps. The start time for the breakdown can be given as an input. At that time the flap closes fully or stays in the current position. In a similar way, conditions for the breakdown of power plants, finishing lines, flare flaps, compressors etc. were implemented. The simulation speed ratio (sim.time / real time) is about 17. Reason for this high performance is the fact that a 3 equation model is used for flow modeling [2], [3], [4].

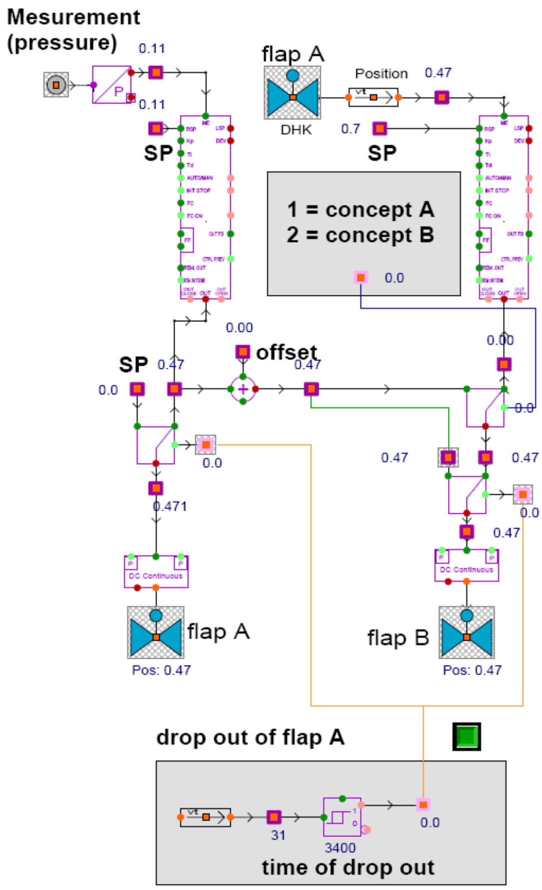

Fig. 1 Control unit for two interacting flaps

Although the gases are mostly saturated after a wet scrubber, the influence of humidity on flare- or pressure losses can be neglected.

2.1 Validation

The model has been validated in terms of pressure, mass flow rate and gas temperature. Main focus were the pressure levels and the pressure dynamic. Both values are important for the analyses of flare losses and incidents in the network. Because of the use of a 3 equation model it is not possible to simulate condensation with this model. To correct the mass flow rate the gas also consists of a certain amount of non condensable water. The analyzed distribution system affords a lot of useful live measurement signals for validation. Fig. 2 shows two results of the validation. Two comparisons between measured pressure and simulated pressure at two significant points of the net were reproduced. The simulation follows the measurement with good accuracy. In the lower digram a small phase shifting is visible which might be founded on deviations of the pipe length. Most important for incident analyses are the correctness of the pressure peaks. Pressure peaks are responsible for flare losses and for facility breakdown. The pressure peaks show a good compliance between measurement and simulation.

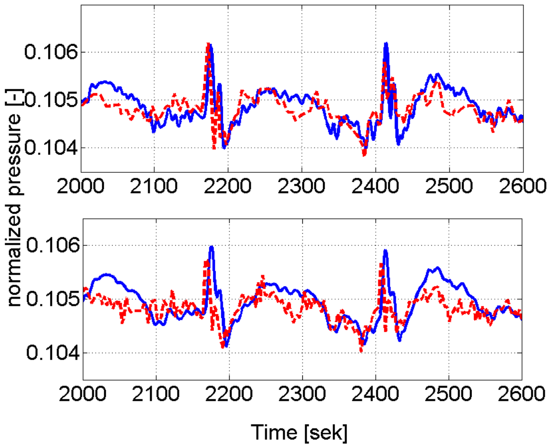

Fig. 2 Comparison between measurement and simulation at two points of the distribution system

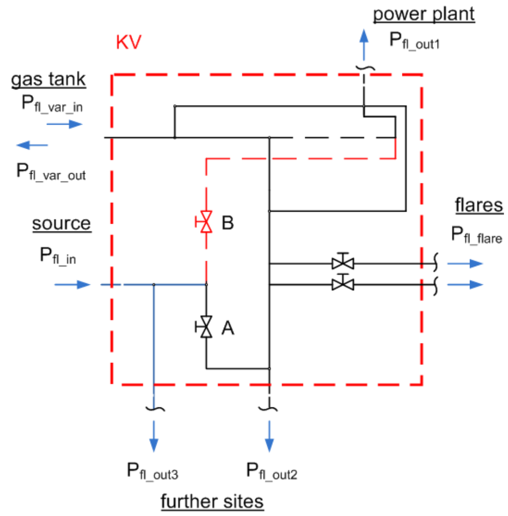

Fig. 3 Scheme of a planed reconstruction

3 Open questions in industrial gas distributions systems

One conclusion of the validation is that the model delivers results which can be used to evaluate planned, new network configurations. A lot of steel works or other complex plants have been extended or modified several times during their lifetime and underlie a continuous change. So for plant operators, it is important to know how modifications will change the operating behavior in advance.

3.1 Comparison of different net configurations

Associated with changing terms of net configurations the control system of the network will change too. The simulation model allows to compare different net configurations with different control concepts. A concrete example is a part of the distribution pipe network, where a higher pressure level than in the other parts of the network is required. Fig. 3 shows a scheme of the analyzed situations. The source (blast furnace) provides different consumers including the power plant of the steel work. The marked blue area is part of the net with higher pressure level. The pressure is controlled by flap A. In the original configuration all gas consumers are provided by this single pipeline. To assure the supply of the power plant in the north of the net, a second pipe is additionally planned. The new configuration has now two flaps (A and B) and two pipes to supply the whole net. How does the new net configuration effect the supply of the facilities? How do flare losses react on the changed conditions?

3.2 Comparison of different control concepts

The new configuration has also a big influence on the control of the net part with higher pressure, around the source. To control the high pressure area after the modification of the network two flaps are necessary. For two flaps there are a few appropriate control concepts. Each concept has different influence on the dynamic behavior of the gas distribution system. What are the differences in the dynamic behavior of each concept? Which concept leads to the most constant pressure conditions in the high pressure area and even directly in front of the facilities? Which concept prevents flare losses most?

3.3 Incident analyzes

An other important factor is the behavior of the systems in case of different incidents. With the numerical model it is possible to analyse the effects of a certain incident on new net configurations. Even the control system has to be tested for the new conditions. Two considerations were taken into account.

- each consumer must have shut down conditions to prevent a falling of the net pressure below a certain pressure level. Due to this context, the gas production has direct influence on the operating point of each facility.
- on the other hand a shut down of a plant can be triggered by internal problems. Then the net has to react on these changed boundary (consumer) conditions.

The pressure level in the net has to be ensured. The operation of all other plants has to be guaranteed. No other plant should be influenced by the incident. How can the net fulfill the requirements?

4 Losses in distributed pipe networks

There are mainly three different kinds of losses in a distribution system:

- pressure losses
- thermal insulation losses
- chemical losses

More in detail, losses can be analyzed by investigating the difference of the medium pressure, the medium flow velocity, the medium temperature, the geodetic height and the mass flow rate of the medium between net inlet and net outlet. The inlet mass flow does not necessarily have to be the utilized mass flow, because if the pressure at one point of the net reaches a maximum limit, the flares open and try to stabilize the pressure levels inside the network. The gas is then lost through the flares. Tab. 1 shows the magnitude of different losses. Column one includes specific losses caused by wall friction and internals (valves, orifices, etc.). Column two describes the specific losses caused by changing flow velocity. This term is nearly zero, and can be neglected. The third column describes the thermal losses due to imperfect insulation. The next column is basically the heating value of the gas. Assumed is a heating value between natural gas (40000 kJ/kg) and blast furnace gas (3000 kJ/kg). Chemical losses are the difference between mass flow input and output represented by the amount of gas. The last column represents the specific losses caused by different geodetic heights of in- and outlets. For the calculation of the specific losses in Tab. 1 typical pressures, velocities and geodetic heights were assumed.
The losses of potential energy seems to be insignificant, but for mass flow rates higher than 200 kg/s they should be considered. Tab.1 shows that the reduction of flare losses should have first priority. Thermal losses strongly depend on the condition of the insulation of the system. Better insulation leads directly to less thermal losses.

Tab. 1 Dimension of losses in large gas distribution systems

specific Energy	e_{pot}	e_{kin}	e_{therm}	e_{chem}	e_{geo}
kJ/kg	6	0.005	50	3000	0.2

5 Quantification of different net- and control configurations

The simulation delivers a lot of possible configurations which can be compared and analyzed. The requirements demanded from the system are defined by the operators. One goal of net development and configuration is a highest possible, constant pressure as well as lowest flare losses. To quantify the energy efficiency of the net, and to get the possibility to compare different configurations objectively, two coefficients have been developed.

5.1 Coefficients for quantification

The idea for the two coefficients is based on the Bernoulli equation [3]. Using Bernoulli Equation two coefficients can be generated to quantify pressure and flare losses. For a single pipeline, losses can be calculated by the energy difference between in- and outlet. The specific energy of a media flow through a certain cross section can be calculated with Eq. 1.

$$e_{fl} = g \cdot z + \frac{p}{\rho} + \frac{\dot{m}^2}{2 \cdot \rho^2 \cdot A^2} + u + h_u \tag{1}$$

The energy loss in a single pipeline with only one in- and one outlet can be calculated by Eq.2.

$$e_l = \Delta e = e_{fl_{out}} - e_{fl_{in}} \tag{2}$$

For ramified networks with n inlets and m outlets specific values cannot be added; Eq. 3.

$$\sum_{i=1}^{n} e_{fl_{in}} \neq \sum_{i=1}^{m} e_{fl_{out}} + e_l \tag{3}$$

For that reason for a widely ramified network absolute values have to be used to calculate the losses. Eq. 1 has to be extended with the mass flow rate $\dot{m}$.

$$P_{fl} = \dot{m} \cdot g \cdot z + \dot{m} \cdot \frac{p}{\rho} + \frac{\dot{m}^3}{2 \cdot \rho^2 \cdot A^2} + \dot{m} \cdot u + \dot{m} \cdot h_u \tag{4}$$

For absolute values the losses in a widely ramified network (n inlets, m outlets) can be calculated by:

$$\sum_{i=1}^{n} P_{fl_{in}} = \sum_{i=1}^{n} P_{fl_{out}} + P_l \tag{5}$$

For the following considerations it makes sense to simplify the P_{fl} term. Usually the geodetic hight and the kinetic energy are small in comparison with the other terms; see Tab. 1. These two terms can be neglected, so that Eq.4 can also be written in Eq.6.

$$P_{fl} = \dot{m} \cdot \frac{p}{\rho} + \dot{m} \cdot u + \dot{m} \cdot h_u \tag{6}$$

The further calculation are based on Eq. 6. The equation shows the three crucial quantities for losses in large widely ramified industrial networks.

5.1.1 Thermal losses

Thermal losses hardly depend on the dynamic of the system. They mainly depend on the insulation of the pipe network. The quality of the insulation is also a measurement for the amount of thermal losses in a ramified network. In fact thermal losses also depend on the different mass flow rates distribution in the ramified network. It might be useful to start consideration about a thermal loss coefficient, for systems which have a bad insulation. In this paper thermal losses wont be considered. It is assumed that the gas temperature in the system has nearly constant temperature, which is acceptable for some cases. Heat recovery systems are usually installed before the gas enters the distribution grid. Distribution systems with high gas temperatures are mostly well insulated.

5.1.2 Flare losses - Flare loss coefficient (F_{LC})

If the pressure exceeds an upper limit at a certain point, the flares flaps open to decrease and stabilize the net pressure. In dependency on the magnitude of the disturbance, a certain amount of gas is lost. To calculate the lost energy, Eq. 6 has to be integrated over the time of open flare flaps. The flare loss coefficient (F_{LC}) in its simplest form can be defined as shown in Eq. 7

$$F_{LC} = \frac{\sum P_{fl_{flare}}}{\sum P_{fl_{in}}} \quad (7)$$

In Eq. 7, expression $P_{fl_{flare}}$ is the power flow rate passing the flare and $P_{fl_{in}}$ is the power flow rate which enters the control volume. Fig. 3 illustrates the different values. Considering that the flow direction might change in some pipes Eq. 7 has to be modified. Reason for variable mass flows could be a gas tank which gets charged or discharged. For the F_{LC} it is only from interest if a mass flow enters a certain control volume. The modified F_{LC} can be written as shown in Eq. 8.

$$F_{LC} = \frac{\sum P_{fl_{flare}}}{\sum P_{fl_{in}} + \sum P_{fl\_var_{in}}} \quad (8)$$

Considering that the P_{fl} term consists of three energy parts (e_{pot}, e_{chem}, e_{therm}) where e_{chem} is at least 60 times bigger than the others, F_{LC} can be converged by Eq. 9, under constant gas quality conditions.

$$F_{LC} \approx \frac{\sum \dot{m}_{flare}}{\sum \dot{m}_{fl_{in}} + \sum \dot{m}_{fl\_var_{in}}} \quad (9)$$

$\sum \dot{m}_{fl\_var_{in}}$ is only that part of the variable mass flow, that enters the control volume. The outgoing part must not be considered in Eq. 9. Under stationary conditions the value of F_{LC} is between 0 and 1. 0 means no flare losses, 1 means that the whole mass flow entering the system is lost through the flares. Under transient conditions the value of F_{LC} can temporary presume values greater 1 and smaller 0, caused by the storage capacity of the system. The mean value always has to be between 0 and 1, also for transient conditions.

5.1.3 Pressure losses - Pressure loss coefficient (P_{LC})

Pressure losses are caused by wall friction or internals (valves, orifices, bends, etc.). Indirectly flare losses are also pressure losses. Flare losses lead to pressure decrease in the net. To reach the originally pressure level again, energy has to be delivered to the system. For the F_{LC} all terms of the power flow rate have been used; although it has been shown that the index can be reduced to an expression of mass flow rates. To investigate the pressure losses in an widely ramified network, only the pressure term from the power flow rate in Eq. 6 has to be considered.

$$P_{fl} = \dot{m} \cdot \frac{p}{\rho} \quad (10)$$

Due to these considerations the pressure loss coefficient (P_{LC}) can be defined as shown in Eq. 11.

$$P_{LC} = \frac{\sum P_{fl_{out}} - \sum P_{fl_{flare}}}{\sum P_{fl_{in}}} \quad (11)$$

In Eq. 11 $P_{fl_{out}}$ is the power flow rate leaving the control volume. The P_{LC} is an index for pressure losses in a system. A higher pressure loss index means that the whole net has less losses caused by friction or internals. The losses depend on the distribution of the different gas flows in the different pipes. Different gas flows lead to different velocities and consequently to different total pressure losses. The P_{LC} can have values between -1 and 1. 1 means that there are no pressure losses in the system. -1 means that the whole entering power flow is lost through the flares. Flare losses are also pressure losses because they lead to reduced pressure in the system. For systems with variable flows the index has to be extended; Eq. 12.

$$P_{LC} = \frac{\sum P_{fl_{out}} + \sum P_{fl\_var_{out}} - \sum P_{fl_{flare}}}{\sum P_{fl_{in}} + \sum P_{fl\_var_{in}}} \quad (12)$$

In dependency on the current flow direction in the pipe, the flow has to be added either to the counter or to the denominator [5], [6].

Incorporation of compressors

Compressors are often part of complex gas distribution networks. They are necessary to guarantee a certain pressure level and therefore the supply of all facilities like power plants or finishing lines. Fig. 4 shows the modified conditions in the example net. The control volume was extended and includes a compressor, which delivers gas into the net in case of decreasing pressure or deflates gas into the gas tank in case of too high pressure. The compressor applies energy to the system. This energy has to be considered to calculate the indices P_{LC} and F_{LC}. The applied power can be calculated by Eq. 13.

$$P_{comp} = P_{el} \cdot \eta \quad (13)$$

For the F_{LC} the power of the compressor has to be added to the denominator. F_{LC} then can be calculated as shown in Eq. 14.

$$F_{LC} = \frac{\sum P_{fl_{flare}}}{\sum P_{fl_{in}} + \sum P_{fl\_var_{in}} + \sum P_{comp}} \quad (14)$$

For the P_{LC} only that part of the applied energy must be used which is responsible for pressure increase. An estimation of the technical work can be made with the knowledge of the compressor. To take this consideration into account, a factor (ϵ) is implemented in the equation.

$$P_{LC} = \frac{\sum P_{fl_{out}} + \sum P_{fl\_var_{out}} - \sum P_{fl_{flare}}}{\sum P_{fl_{in}} + \sum P_{fl\_var_{in}} + P_{comp} \cdot \epsilon} \quad (15)$$

Both indices help to compare different net configurations or control concepts. It is possible to estimate the energy savings or the pressure constancy. The pressure equality can be very important for operators of facilities, to prevent incidents caused by improper pressure levels. This leads to further even higher costs.

6 Analysis of different net configurations

In section 3, an example for a typical situation in large gas distribution systems was given. In a first investigation an existing configuration (flap A) was compared

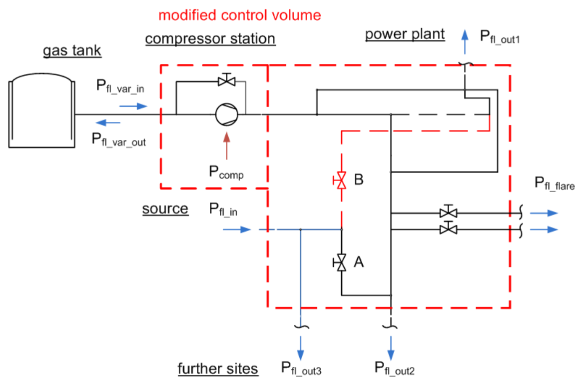

Fig. 4 Scheme of a planed reconstruction including a compressor (extended control volume)

with a planned modified configuration (flap A and B). The simulation shows that the expectations to increase the pressure level near the power plants were achieved. A second result was that disturbances stronger spread into the low pressure net. In a second step different control concepts were investigated. Fig 5 shows 3 different control concepts in comparison.

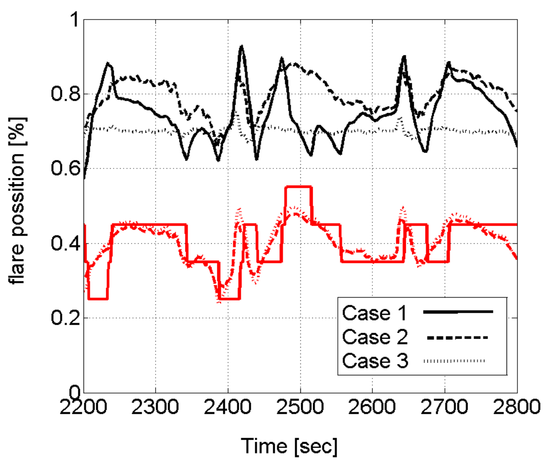

Fig. 5 flare positions for different control concepts

- case 1: split range control, if one flap is out of range for some seconds, the other flap in- or decrease its position about $x\%$
- case 2: both flaps control the pressure in the blue area, offset between the flap position 40%
- case 3: one flap controls the pressure in the blue area, second flap controls the position of first flap (position 70%)

Each control concept has few parameter to optimize. In a first approach each concept was heuristic optimized. The results of each concepts were compared. Fig. 6 shows the pressure versus the time at two differ-

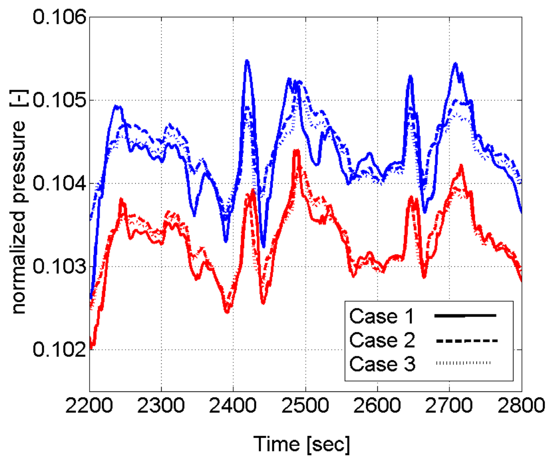

Fig. 6 similar pressure history at different measure points in the north of the gas net

ent points of the net. The point represented by the red line shows very similar results of the pressure history for each control concept. The point represented by the blue line shows little higher differences but nevertheless the pressure histories show similar characteristics. Both measure points are in north of the gas net. In the south of the net (direction $P_{fl_{out2}}$) the system shows a different behavior. Fig. 7 shows the pressure his-

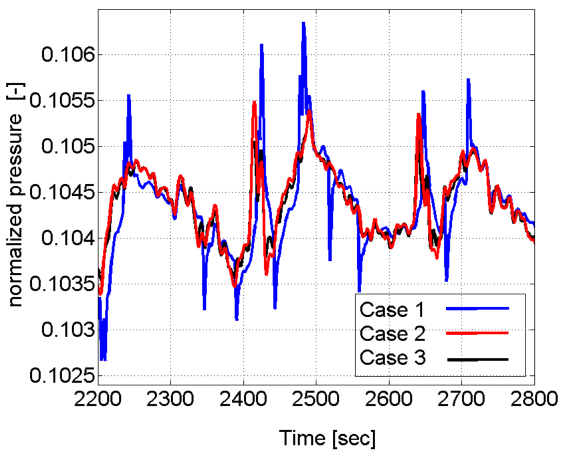

Fig. 7 different pressure history at a measure point in the south of the gas net

tory at a point in the south of the net. Concept 2 and 3 have nearly the same behavior, concept 1 shows huge pressure peaks. These pressure peaks are harmful because facilities might breakdown. The simulation helps to find phenomena and causalities in the net. The simulation shows that control concept 1 has significant disadvantages with respect to pressure equality. Next step should be the investigation of the energy loss behavior of both concepts, in case of disturbances.

7 Consideration regarding incident analyses

The blast furnace feeding behavior is very dynamic. In case of disturbance the mass flow can double within few seconds for a period of 20 seconds. In some cases the gas production breaks down for some minutes. Both cases lead to massive pressure fluctuations which might lead to facility breakdown. In that context analyzing different possible incidents is very important to estimate the impacts on the net. The simulation shows that interferences of different incidents can lead to chain reactions of malfunctions of different facilities. To optimize a network with respect to the input energy, incident analyses have to be done. Responsible for the breakdown is almost ever a too high or too low pressure level. From Fig. 6 and Fig. 7 it can be seen

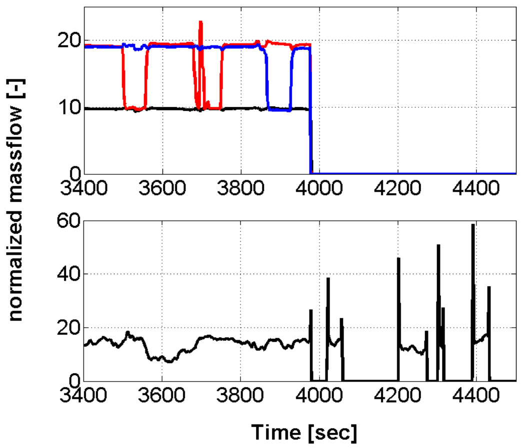

Fig. 8 flare loss coefficient versus time

how difficult it is to estimate the pressure level in the whole network. In some areas the pressure level will decrease, in some increase and in other they stay nearly constant. The pressure loss coefficient quantifies the averaged pressure level in the whole net. The higher the P_{LC}, the higher the averaged pressure level. The average value of the P_{LC} further gives information about the equality of the pressure and is therefore an index how probable it is that a facility breakdown occur. Fig. 8 shows an example how a mass flow discontinuity of a source (blast furnace) can lead to the breakdown of finishing lines in the simulation. In the upper picture the lines will not restart after brake down. They have to be activated again by hand. The lower picture shows a plant which has a hysteresis implemented. If the pressure stabilizes for some seconds the plant restarts again. The high mass flow rates after the restart are caused by the switching procedure. Nevertheless in some cases the start up procedure directly causes a break down of the finishing line again.

8 Estimation of simulation results

As shown in section 4 pressure losses are not the main losses in ramified gas distribution systems, but they can lead to indirect losses like flare losses or facility break down. From that point of few, it can be useful to investigate the pressure constancy. To estimate the results the operators have to define criteria for quality of network operation. It might be possible that different operators have different inconsistent requirements. Nevertheless operator requirements do have first priority for estimation. The described indices allow to decide, whether a certain net configuration causes higher flare losses or a lower pressure level than others. Fig.

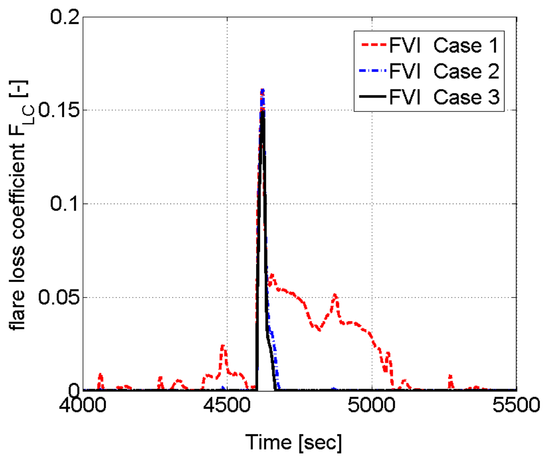

Fig. 9 flare loss coefficient versus time

9 shows the result of an incident analysis for the situation described above. The blast furnace mass flow increases for some seconds, and returns to normal value again. The three control concepts have been compared. We observe that concept 2 and 3 have similar behavior. Concept one shows a different behavior. The F_{LC} shows the different behavior of the 3 concepts. Concept one needs much longer until the disturbance disappears. This leads to higher flare losses. Even the P_{LC} shows worse history for concept one. P_{LC} and F_{LC} always have to be evaluated in common for two or more configurations. Only if F_{LC} decreases, it makes sense to improve the pressure loss behavior.

9 Calculation of energy saving

Both indices have the dimension of a power ratio. In order to calculate the energy saving between two configurations one approach is to integrate the savings over the time. This can be expressed by Eq. 16.

$$E_{save} = \int_{t=0}^{T} \left(\sum_{i=0}^{n} P_{fl_{in}i} \right) \cdot \Delta F_{LC} \cdot dt \qquad (16)$$

Fig. 10 shows the interpretation of Eq. 16. Case 1 and Case 2 were compared during an incident. First configuration includes only flap A, the second configuration includes the new pipe between source and the power plants. For both nets a disturbance was set at a time of 4500 seconds. It can be seen that there is only a little difference between the extended and the original

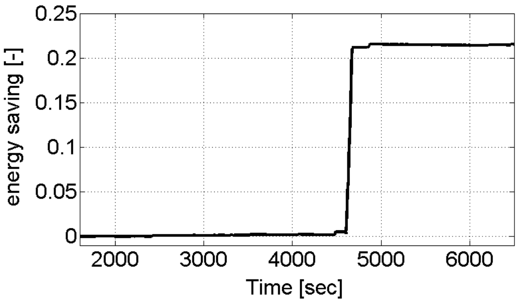

Fig. 10 Energy savings between two net configurations

situation, observable by the little gradient of the line between $T = 2000$ and $T = 4000$. But in case of an incident high energy saving behavior accrues $T \approx 4600$. For long simulation periods a statistical analyses can be useful. During the simulation the coefficients will be calculated discrete. An averaged value gives information about the efficiency of the configuration within one value. Tab. 2 shows a statistic analyses for a time span

Tab. 2 Averaged P_{LC} and F_{LC} values for normal mode

value	calculation	config. flap A	config. flap A and B
P_{LC}	average	0.979	0.993
P_{LC}	standard deviation	0.047	0.041
F_{LC}	average	0.0085	0.0083

of 8 hours simulation of a blast furnace gas distribution system. Again the two different configurations (flap A versus flap A & B) have been compared. The results show that the planned new configuration will increase the efficiency of the network. An averaged value gives information about efficiency of the configuration for a certain period of time. First the F_{LC} has to be considered. Using Eq. 10 the energy saving can be calculated. The amount of saving depends on the inlet power mass flow.

10 Conclusion and perspectives

In large gas distribution systems there are a lot of questions which can not be answered easily. Questions in context with the dynamic behavior of the system; flow dynamics which lead to flare losses and/or to the breakdown of different plants connected to the distribution systems, can be analyzed with the model. Net operator have to define the breakdown conditions for each plant; but how can those conditions be tested? The prepared model gives the possibility to answer similar questions prior to the implementation. Different control concepts can be compared in terms of safety, security of supply and cost reduction. Therefore incident analysis is one of the main goals of the model. To quantify results, different criteria are crucial: Pressure level at different points of the net, pressure equality inside the net, energy losses during standard operations, energy losses during incidents. The two presented coefficients help to objectively quantify the quality of the net regarding to energy losses. The coefficients are only meaningful if they are related to the behavior of the units, especially in case of a breakdown.

11 Symbols

Tab. 3 Symbols and variables

name	discribtion	unit
A	area	kg/s
$\dot{m}$	mass flow	kg/s
$\dot{m}_{flare}$	mass flow through flare	kg/s
$\dot{m}_{fl_{in}}$	mass flow into CV	kg/s
$\dot{m}_{fl_{out}}$	mass flow out of CV	kg/s
p	pressure	Pa
u	spec. internal energy	J/kg
ρ	density	kg/m^3
h_u	heating value	J/kg
e_l	spec. lost energy	J/kg
e_{fl}	spec. energy of flow	J/kg
P_l	lost power	J/s
P_{fl}	power flow	J/s
P_{fl_var}	variabel power flow (changing direction)	J/s
$P_{fl\_var_{in}}$	variabel power flow rate (into CV)	J/s
$P_{fl\_var_{out}}$	variabel power flow rate (out of CV)	J/s
$P_{fl_{in}}$	power flow rate into CV	J/s
$P_{fl_{out}}$	power flow rate out of CV	J/s
$P_{fl_{flare}}$	power flow rate through flare	J/s
P_{comp}	power of compressor	J/s
P_{el}	electrical power of compressor	J/s
η	efficiency	
ϵ	weighting factor	
P_{LC}	pressure loss coefficient	
F_{LC}	flare loss coefficient	

12 References

[1] Heinz Zoeble and Julius Kruschik. *Stroemung durch Rohre und Ventile*. Springer Verlag Wien - New York, 1982.

[2] http://www.apros.fi/en/.

[3] N.I.Kolev. *Multiphase Flow Dynamics 1*. Springer, 2002.

[4] S. V. Patankar. *Numerical Heat Transfer and Fluid Flow*. Series in Computational Methods in Mechanics and Thermal Sciences. Hemisphere Publ. Corp., Washington, New York, London, 1980.

[5] S. Jakubek A. Werner M. Himmelbauer M. Buchsbaum K. Haider M. Haider R. Schimon, T. Henrion.

Methoden zur Verbesserung der Energieeffizienz mittels dynamischer Simulation am Beispiel eines integrierten Huettenwerks. *ASIM Treffen 2010 - Simulation technischer Systeme, Grundlagen und Methoden in Modellbildung und Simulation*, pages S. 103 – 113., 2010.

[6] R. Schimon. Dynamic simulation of different gas distribution systems in integrated iron and steel works. *Proceedings of the C&SEE International Solid Waste Management Symposium*, pages S. 9 – 15, 2009.