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Gas Pipeline Accumulated Energy for Peak Shaving Power Plants

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Abstract: The paper is presenting the natural gas supply for power plant used for peak shaving purposes in daily power supply for Slovenia. The 130 MW power plant is situated at the gas pipeline branch. To assure proper gas delivery capacity the minimum gas pressure at the branch must be respected. The power network at the power plant enables the power distribution to users. The paper is presenting the gas pipeline operator activities to enable the daily peak supply for power plant productions. The operator has to respect the continuous gas supply to the pipeline grid at border stations. Supply includes the necessary gas quantities for power station operation. The peak supply must be achieved only by using pipeline inventory and compressor station operation according to predicted power plant production based on pipeline system simulation.

Key-Words: Energy Management System, Simulation of Power Systems

1 Introduction

Slovenian national gas pipeline system operator Geoplin – plinovodi d.o.o. operates the pipeline connecting three countries: Austria, Italy and Croatia. At the border connection points and at the delivery points in the country is necessary to respect the Gas directive issued by EU Parliament in 1998. According to this directive the pipeline operator and different shippers are present on border stations. National pipeline operator uses Entry – Exit flow model for national network. Pipeline operator is responsible for gas flow capacities and physical pipeline balancing at the border point. The shippers supply the gas quantities according to transportation contracts with operator. System operator has to face with high oscillations in the gas delivery in the country.

To enable the use of the gas in power plants both all parties - the gas the Pipeline operator, shipper and Power producer - must benefit. In the presented cases the pipeline operator benefits on increasing gas capacities in the pipeline system the shipper increases the gas market and the Power plant operator benefits on price difference in power delivery for peak hour against the delivery in low tariff hours.

The peak gas delivery for power station must be enabled by Gas system operator. He uses the pipeline inventory to create the time difference in peak between gas and power distribution system. To be able to manipulate with pipeline inventory gas pipeline control system must be able to follow the current delivery, compare it to the supply and enable physical balancing. The recent solution has been transient simulation model. This has been proven as a successful method to control the gas throughput oscillations in the pipeline grid [1]. It is also proven that the advantage of the transient optimizer over steady state optimizer increases directly with the transient activity in the pipeline [2]. This was accepted as basis to upgrade the existing control system to optimize the flow capacity according to different delivery requirements.

2 Accumulated Energy

To control the gas transport and balance between deliveries and supply two basic principles in pipeline grid mathematical solution were introduced:

- pipeline system segmentation
- problem solution in different time scale.

The pipeline segments are chosen according to mainline and compressor stations where pressure and flow regulation is possible. The segmentation system is presented on Fig.1, which shows Slovenian pipeline grid with possibly supply and main delivery points. The Table 1 on Fig.1 shows the variables connecting the segments and time frame in which the calculations can be provided.

The purpose of this article is to present the use of pipeline inventory for peak shaving gas delivery using the mentioned mathematical solution.

The gas flow can be expressed as the power (P) and the gas volume as energy (E). The pipeline inventory, which makes the difference in energy transmission between power and gas distribution systems, is presented as accumulated energy (AE).

The contracted gas flow (P) on the intake points of the system is achieved with remote flow regulation on these stations. The flow oscillations at delivery points in the system result in inventory change (i.e. AE change) inside the segments. The AE change can only be done in the limits which depend from boundary conditions and time.

The accumulated energy limits are calculated according to equations (1) and (2).

$$AE_{LOW\,LIMIT}(t) = \sum_{k=1}^{No.\ of\ Segments} \left[\frac{p_{LOW\,LIMIT\,k}(t, B.C.)}{T_k(t, B.C.)\ \ z_k(p_k, T_k)} \ \ \frac{GCV_k\ \ V_{geomk}\ \ T_S}{p_S} \right] \quad (1)$$

$$AE_{HIGH\,LIMIT}(t) = \sum_{k=1}^{No.\ of\ Segments} \left[\frac{p_{HIGH\,LIMIT\,k}(t, B.C.)}{T_k(t, B.C.)\ \ z_k(p_k, T_k)} \ \ \frac{GCV_k\ \ V_{geomk}\ \ T_S}{p_S} \right] \quad (2)$$

where:

$AE_{LOW\ LIMIT}$ … minimal accumulated energy requested for pipeline operation [GJ]
$AE_{HIGH\ LIMIT}$ .. maximal accumulated energy possible during pipeline operation [GJ]
$p_{LOW\ LIMIT\ k}$ … minimal requested operating pressure in observed pipeline segment "k" as function of time "t" and boundary condition "B.C." [bara]
$p_{HIGH\ LIMIT\ k}$ … maximal allowed operating pressure in observed pipeline segment "k" as function of time "t" and boundary condition "B.C." [bara]
T_k ………… gas temperature in observed pipeline segment "k" [K]
z_k ………… gas compressibility at pressure p and temperature T in segment "k" [-]
GCV ……… gas calorific value in observed pipeline segment "k" [MJ/m^3]
$V_{geom\ k}$ ……… geometric volume of observed pipeline segment "k" [m^3]
T_S, p_S ……… temperature and pressure defining the standard condition [K, bara]

For the gas delivery day the transient simulation calculates the AE depending from supply, delivery and time of the day. The accumulated energy is calculated according to:

$$AE(t) = AE_{t_0} + \sum_{i=1}^{No.of\ Supplies} \left[\int_{t_0}^{t} P_{SUPPLY\ \ i}(t)\ dt \right] - \sum_{j=1}^{No.of\ Deliveries} \left[\int_{t_0}^{t} P_{DELIVERY\ \ j}(t)\ dt \right] \quad (3)$$

where:

$AE\ (t)$ …… transient of accumulated energy [GJ]
AE_{t0} …….. accumulated energy at the beginning of the transient [GJ]
$P_{SUPPLY\ i}$ … one of supplies gas source power [MW]
$P_{DELIVERY\ j}$ ... power of one delivery [MW]

The gas power plant (GPP) operation time interval [t_x,t_y] and power peak P_{GPP} (t) can be determined by following condition:

$$\left[AE(t) - \int_{t_X}^{t_Y} P_{GPP}(t)\,dt \ \ \geq \ \ AE_{LOW\,LIMIT}(t) \right] \ \Rightarrow \ t_x,\ t_Y,\ P_{GPP}(t) \quad (4)$$

what indicates that the difference between accumulated energy AE(t) and the time dependent peak power P_{GPP} (t) must be greater than minimal accumulated energy $AE_{LOW\ LIMIT}$(t) requested for pipeline operation along observed transient.

The time dependent procedure is presented on Fig.2.

Power plant peak shaving enables the power plant operator to store the gas in case they do not need the power for nominated day.

The expression defining the temporary storage capabilities takes into account that the accumulated energy transient AE(t) and stored gas energy P_{GPP}(t) can not exceed the maximum

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accumulated energy $AE_{HIGH\,LIMIT}(t)$ allowed by pipeline characteristics and boundary condition:

$$\left[AE(t) + \int_{t_x}^{t_y} P_{GPP}(t)\,dt \;\leq\; AE_{HIGH\,LIMIT}(t) \right] \Rightarrow \max P_{GPP}(\max P_{SUPPLY}(t)) \quad (5)$$

In nomination procedures it is possible to request from operator to store the gas being supplied into the system but not used in nominated day. This difference must be treated separately from energy allocation.

3 Energy Management System

To enable the control of the entire energy supply by control computer system the energy system was divided in two strongly connected Systems:

- (Energy Management System) GMS - dealing with different customers contracts, nominations, forecasting the real demand for customers and customer groups, nomination and allocation procedure according to allocation rules,

- process computer control of pipeline grid GCS (Gas Control System) using SCADA (Scan And Data Acquisition System) to control pipeline grid and GMoS (Gas Modelling System) implementing real time transient simulation system to predict pipeline state in the future. The main predictions are for daily use of inventory, compressor operations and gas storage operations. In prediction the power plants nominations are taken into account. The system operation is prepared according to nominated quantities for planned power production.

The Slovenian pipeline grid (Fig.1) is supplied from two gas sources has three storages outside the country and one compressor station. At this moment we have one power plant in operation for 4 years and more new in planning procedure.

The daily power plant consumption is nearly 30 % of total daily gas consumption in Slovenia. In the case of peak shaving, lasting for 8 hours, the hourly flow is even higher. It is necessary that such increase in flow is simulated and approved by system operator.

4 Simulation of Pipeline System

For simulation the possible distribution of gas energy in the pipeline system the predictive transient simulation is used. The predictive simulation must run before the gas delivery. To be able to run the simulation the following data must be available:

- current real time data from where the simulation is started
- current regulator set points and current compressor operation parameters
- delivery forecast for some customers and nomination quantities specially for power plants
- balanced data for day of delivery (D) between supply and delivery taking into account the change in inventory.

During the gas energy delivery to the power plant the operator is continuously following the pressure and inventory against the predicted values. On Fig.3 one simulated day is presented in comparison with allocated (measured) values. The main variables, pressure at critical point and inventory are presented for simulated and measured values.

The critical pressure at power station location is 32,0 bar. The simulation starting from current real time state at 6 o'clock shoved the minimum pressure 32,6 bar. At the start of delivery the pressure drop showed tendency of higher pressure drop as simulated. The reason was the operation set points of the compressor station. It was necessary to change the compressor station set points.

On Fig.4 the operation head - input flow map of the compressor station is presented. Compressor must operate inside the operating map, which defines necessary flow and pressure difference, according to compressor speed lines.

The operator must achieve the operating condition for the compressor unit on the compressor station location. It is preferable that the operating conditions are in the range of maximum efficiency of 84% in this case, to achieve savings on gas flow usage. Such conditions are not always possible if pressure at critical point is approaching the critical limit, as in this case.

Inside the compressor map on Fig.4 the curve of compressor operating points are shown. It is seen that during the operation of the power plant the compressor was out of optimal efficiency curves approaching surge line. At the end of power plant operation the optimum operating conditions were achieved again shown by square on Fig.4.

If we look back at the Fig.3 we can observe the end of operation of power station. According to higher pressure condition as simulated at app. 15 hours, operator allows higher flow for last hour as nominated by power station operator.

5 Benefits

The benefit of peak gas delivery and temporary storage of the gas we must observe from Gas pipeline operator, Shipper and Power station companies.

Gas pipeline operator :
- the higher efficiency of expatiating the gas transport capacities. The efficiency of capacities, over the year whole year, were increased for 3,5%
- exploitation of gas pipeline inventory as temporary storage
- the operator must consider lower efficiency in compressor station operation. Compared to benefits this is minor problem.

Shipper:
- delivering more gas energy quantities. In the season for the year 2003/2004 the additional energy quantities delivered achieved 1000 GW
- increase number of important customers

The benefit in Power Station Company is:
- producing the power in peak time hours for the same price as in low consumption hours
- no fuel storage needed for additional power production
- achieving higher efficiency on power turbine using gas instead of oil for app. 1%
- improving environment conditions.

6 Conclusion

- The accumulated energy of gas transmission system can be used to deliver peak shaving energy to power stations at different times.
- Gas Control Modeling and Management System with transient operation must be implemented in Gas Company operation enabling the predictive run including the regulator and compressor stations operations.
- Benefits for Gas Pipeline Operator, Shippers and Power Station companies can be achieved.

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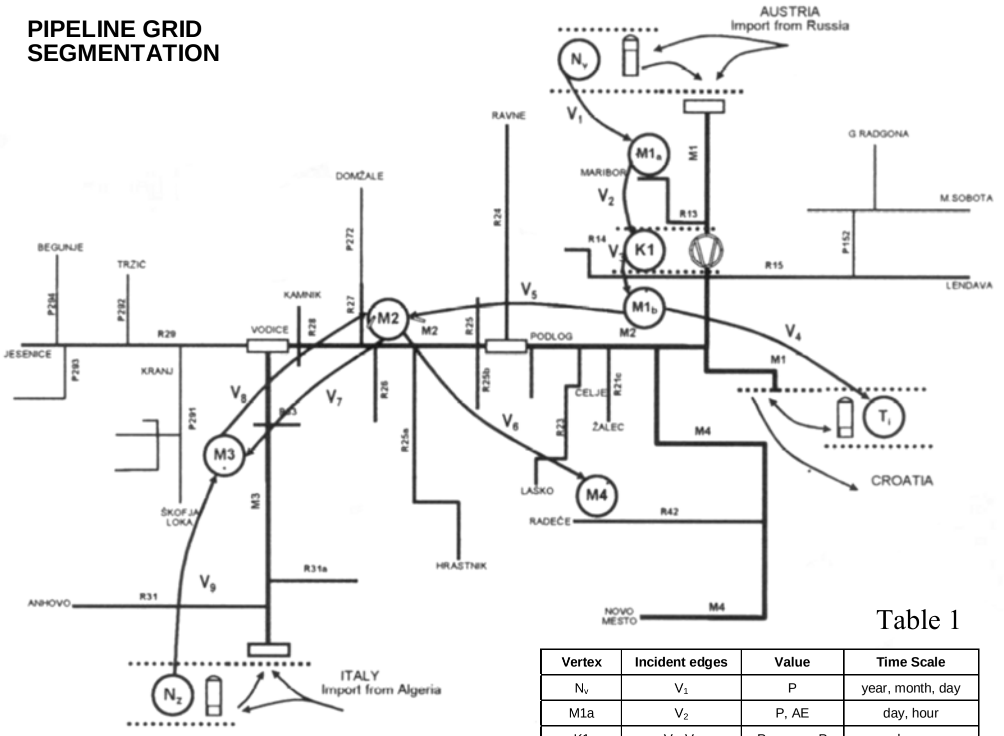

Fig.1: Pipeline segmentation

Table 1

Vertex	Incident edges	Value	Time Scale
N_v	V_1	P	year, month, day
M1a	V_2	P, AE	day, hour
K1	V_2, V_3	$P_{compressor}$, P	hour
M1b	V_3, V_4, V_5	P, AE	day, hour
T_i	V_4	P	year, month, day
M2	V_5, V_6, V_7, V_8	P, AE	day, hour
M4	V_6	P, AE	day, hour
M3	V_7, V_8	P, AE	day, hour
N_z	V_9	P	year, month, day

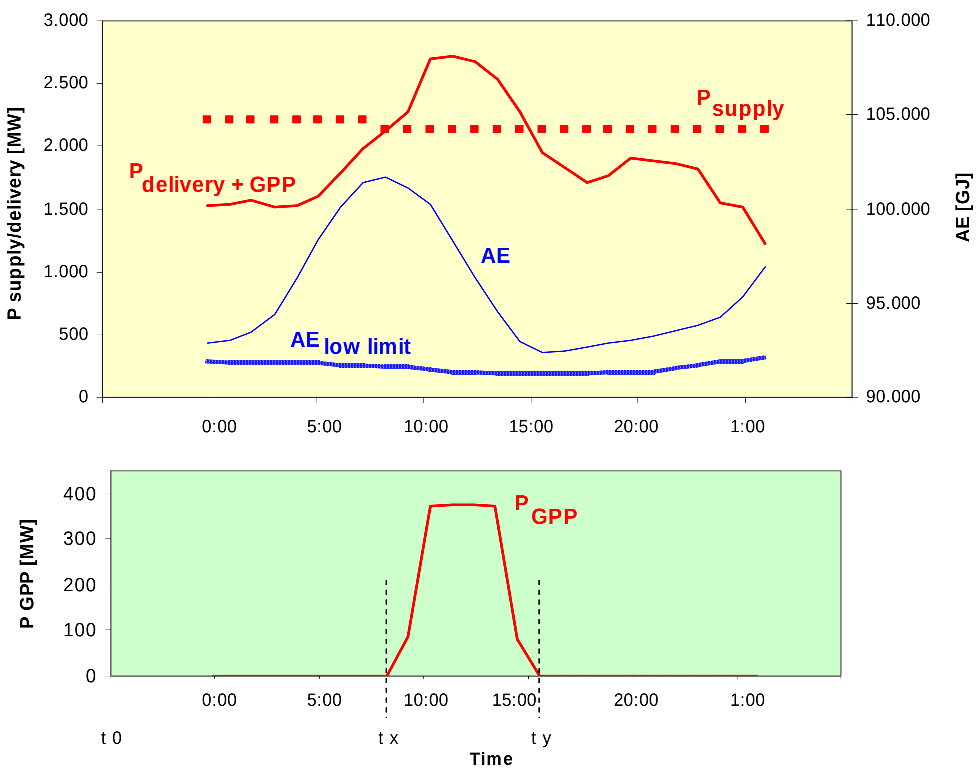

Fig.2: Accumulated energy and power transients

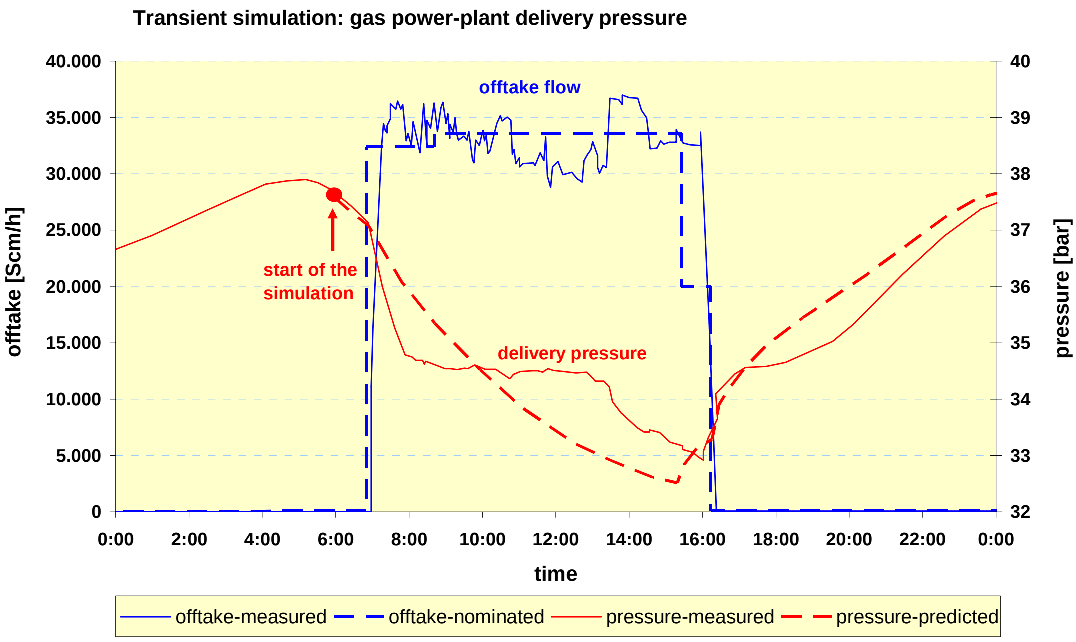

Fig.3: Simulated versus measured peak shaving transient

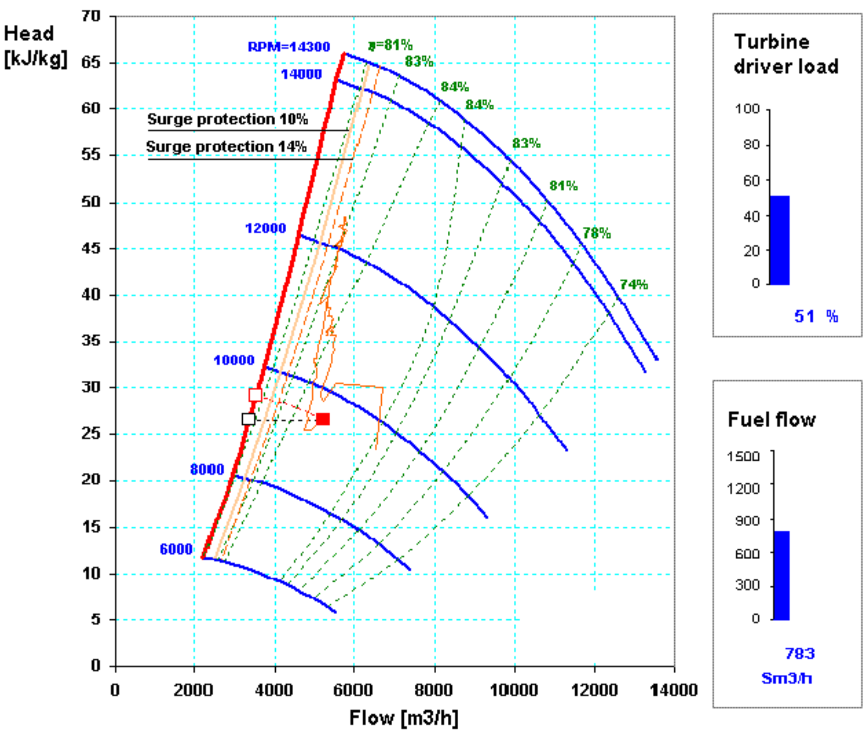

Fig.4: Compressor operation point transient