Gas Network Simulation and Optimization

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June 5, 2014

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Planta Reganosa
Planta El Musel
***
Planta BBG
*
AS Gaviota
CI Irún **
Francia
CI Larrau
Francia
CT Ribadeo
CT Asturias
CT Cantabria
CT Durango
CT Guipúzcoa
CT Coruña
CT León
EC + CT Lumbier
CT Vitoria
AS Serrablo
CT Sabiñánigo
CT Pontevedra
EC Haro
CT Burgos
EC + CT Villar de Arnedo
CT Hostalric
CI Tuy
Portugal
VIP
Portugal
CT Soria
CT Caspe
EC + CT Bañeras
EC + CT Coreses
CT Valladolid
EC + CT Zaragoza
EC + CT Tivisa
Planta Barcelona
CT Segovia
AS Yela
CT Yela
EC Algete
CT San Fernando
CT Toledo
CT Castellón
CT Cuenca
CT Plasencia
EC + CT Paterna
Planta Saggas
CT Mallorca
CI Badajoz
Portugal
EC + CT Almodóvar
EC + CT Alcázar de San Juan
EC + CT Almendralejo
EC + CT Chinchilla
EC + CT Montesa
EC Denia
EC + CT Crevillente
EC + CT Córdoba
CT Jaén
Planta Cartagena
CT Huelva
EC + CT Sevilla
CT Murcia
CT Granada
CT Almería
CT Málaga
CI Almería
Argelia
Planta Huelva
CT Cádiz
CI Tarifa
Marruecos
Planta Santa Cruz de Tenerife
Planta Las Palmas de Gran Canaria
* Enagás posee el 40% del accionariado
** Enagás posee el 90% del accionariado
Enagás Transporte del Norte
*** Pendiente tras el RD-Ley 13/2012, Disp
Transitoria Tercera
LEYENDA
Gasoducto
Tanque GNL
Metanero
Estación de Compresión
Almacenamiento Subterráneo
Conexión Internacional
VIP (Punto de Interconexión Virtual)
Infraestructura en desarrollo
Centro de Transporte
Estación de Compresión + Centro de Transporte
Cargadero de Cisternas
Unidad de Transporte N
Unidad de Transporte S
Unidad de Transporte E
Infraestructura de otros operadores

Technical Sytem Manager

- The Technical System Manager of the Spanish gas network is a private company which, mainly:
  - is in charge of the physical operation of the network.
  - gives advice on network expansions based on past operation and peak day simulations.
- TSM does not have the right incentives to do these jobs efficiently.
- These biased decisions may harm other agents of the system.
- For this reason, we started a joint collaboration with our partner Reganosa LNG company in 2011.

Features of the Spanish gas network

- In practice, it is possible to transport gas between any two points thanks to the high number of compressor stations.
- It is also a quite meshed network, with many routing possibilities.
- Direction of flow in most pipes can vary from day to another.


Norne
Heidrun
Åsgard
Kristin
Haltenpipe
Tjeldbergodden
Ormen Lange
Åsgard transport
Nyhamna
Faroe Is.
Sweden
Statfjord
Norway
Tampen link
Troll
Kollsnes
FLAGS
Heimdal
Zeepipe 2A
Zeepipe 2B
Kårstø
Vesterled
Statpipe
Sleipner
Draupner
St. Fergus
Ekofisk
Denmark
Europipe II
Langeled
Europipe I
Norpipe
Franpipe
Zeepipe 1
Ireland
Easington
Dornum
Emden
Germany
United Kingdom
Netherlands
Zeebrugge
France
Dunkerque
Belgium

Features of the Norwegian gas network

- The Norwegian gas network looks like a tree, where the gas flows from North to South.
- Flow direction is known in advance for most of the pipes.
- As we will see this allows for a simpler resolution of the physical equations of the system.

Mathematical model of a gas network

Definition

Simulation based on a mathematical model of the physical behavior of the network in steady-state. The following elements can be modeled:

- compressor stations,
- regasification plants,
- international connections,
- virtual interconnection points,
- flow control valves,
- pressure control valves,
- closing valves,
- underground storage facilities.

Graph

- The network is modeled as a directed graph.
- The edges represent pipes and have an associated direction.
- The Spanish network can be modeled with around 500 edges and 500 nodes.

Equations for the model

The mathematical model can be deduced from the Navier-Stokes equations for compressible flows:

- Conservation of mass
- Conservation of linear momentum
- Conservation of energy

and the following constitutive laws:

- Newtonian viscous fluid
- State equation for real gases
- Fourier's law for the heat flow

Matrix system

Two families of equations:

- For each node, conservation of mass is computed.
- For each edge, pressure loss is computed.

$$\begin{pmatrix} 0 & \mathcal{A} \\ \mathcal{A}^t & 0 \end{pmatrix} \begin{pmatrix} \mathbf{p} \\ \mathbf{q} \end{pmatrix} - \begin{pmatrix} \mathbf{0} \\ \mathcal{F}(\mathbf{p}, \mathbf{q}) \end{pmatrix} = \begin{pmatrix} \mathbf{c} \\ \mathbf{0} \end{pmatrix}$$

where

- $\mathbf{p}$ is the pressure at the nodes,
- $\mathbf{c}$ is the exchanged mass flow with exterior at the nodes,
- $\mathbf{q}$ is the mass flow at the edges.

Pressure loss

$$\mathcal{F}(p,q) = p(L)^2 - p(0)^2 = -\frac{\lambda(q)\,L}{DA^2} R\,\theta_m\,|q|\,qZ(p_m,\theta_m) - \frac{2g}{R\theta_m}\frac{p_m^2}{Z(p_m,\theta_m)}(h(L)-h(0))$$

being

- λ is the coefficient of friction, computed with Colebrook or Weymouth.
- Z is the compressibility factor, computed with AGA-8 or SGERG-88.

Pressure loss

$$\mathcal{F}(p,q) = p(L)^2 - p(0)^2 = -\frac{\lambda(q)\,L}{DA^2} R\,\theta_m\,|q|\,qZ(p_m,\theta_m) - \frac{2g}{R\theta_m}\frac{p_m^2}{Z(p_m,\theta_m)}\left(h(L)-h(0)\right)$$

being

- λ is the coefficient of friction, computed with Colebrook or Weymouth.
- Z is the compressibility factor, computed with AGA-8 or SGERG-88.

Simulator

$$\begin{pmatrix} 0 & \mathcal{A} \\ \mathcal{A}^t & 0 \end{pmatrix} \begin{pmatrix} \mathbf{p} \\ \mathbf{q} \end{pmatrix} - \begin{pmatrix} \mathbf{0} \\ \mathcal{F}(\mathbf{p}, \mathbf{q}) \end{pmatrix} = \begin{pmatrix} \mathbf{c} \\ \mathbf{0} \end{pmatrix}$$

- These steady-state equations are solved by means of newton-like numeric algorithms.
- They are also the kernel of our steady-state simulator.

Optimization of gas transport networks

Optimization goals

- The optimization goals might be minimize:
  - the self-consumption in the compressor stations,
  - the boil-off gas in the regasification plants
  - the bottlenecks,
  - ...
- The variables to optimize:
  - compression ratio at the compressor stations,
  - decompression ratio on PCVs,
  - flow on the FCVs,
  - flow on the regasification plants, international connections, ...

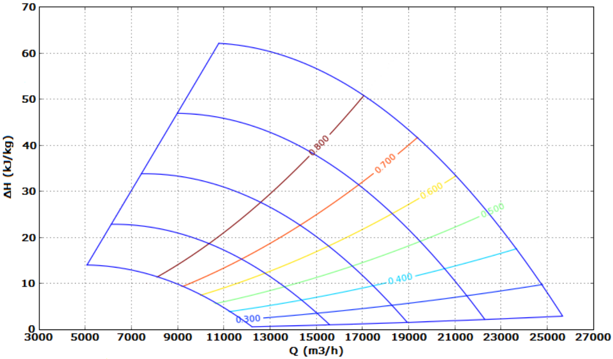
Constraints (I)

The constraints of the optimization problem refer, mainly, to:

1. security of supply:
    - imposed flow at the exit points,
    - minimum pressure at each point of the network,
    - maximum pressure at each point of the network,
    - capacity at each pipe of the network,
    - ...

Constraints (II)

2. Operational ranges in the compressor stations.



Algorithm (I)

In order to optimize the gas transport network, we have developed a two-stage procedure:

1. Disregarding some second order physical effects, a first algorithm obtains an initial solution, which is used to configure the network (compressor stations, PCVs, ...)
2. Based on this configuration, a second algorithm refines the previous solution with the aid of our simulator.

Algorithm (II)

1. Based on Sequential Linear Programming techniques.
2. Based on Control theory techniques.

1st: Sequential Linear Programming

- It consists in iteratively linearize the nonlinear constraints.
- Very good behavior in practice. Limit points are essentially "local optima".
- Its main characteristic is that it does local search based on bounded size steps at each iteration.
- For our purpose, it has two "limitations"
  - Binary decisions/variables are not allowed.
  - It has to be fine tuned based on several parameters.

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1st: Modified SLP

- We have developed a modified version of the SLP which avoids the limitations of classic version:
  - Binary decisions can be made.
  - Few parameters to be tuned.
- It allows unbounded size steps.
- It is more common to observe convergence problems such as cycling in our algorithm.
- Both SLP optimize all the pressures at the nodes and all the mass flows at the edges.

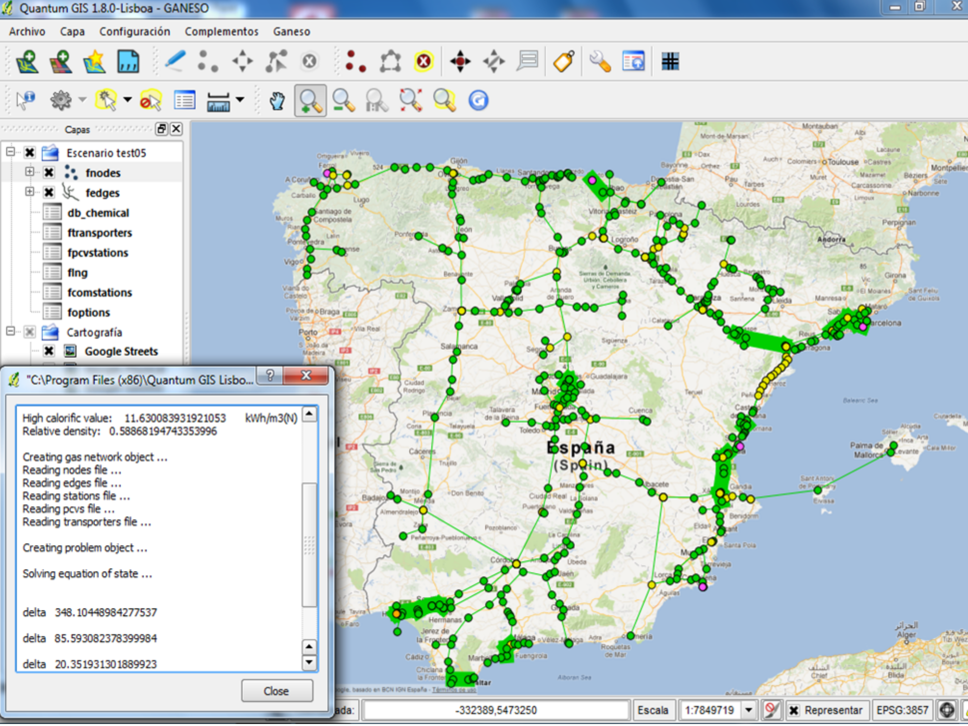
2nd: Control theory

- It starts with a configured network.
- Unlike the modified SLP, it is not able to make decisions.
- It is applied to our simulator, which represents the physical state of the network.
- Implicit constrains: it is not necessary to introduce the pressure loss and the conservation of mass.
- Therefore, less variables to optimize.
- It spends more computational time.

GANESO$^{\text{TM}}$

Definition

- All the mathematical models we have just presented are included in a software called GANESO.
- It stands for GAs NEtwork Simulation and Optimization.
- It is formed by a kernel (implemented in FORTRAN) and a graphical user interface.
- It is not available for purchase.
- Reganosa is continuously using GANESO for their internal operations and to analyze different operational possibilities of the system.
- The tool is rapidly improving thanks to the feedback received from them.


Quantum GIS 1.8.0-Lisboa - GANESO
Archivo
Capa
Configuración
Complementos
Ganeso
Capas
Escenario test05
fnodes
fedges
db_chemical
ftransporters
fpcvstations
flng
fcomstations
foptions
Cartografía
Google Streets
"C:\Program Files (x86)\Quantum GIS Lisbo...
High calorific value: 11.630083931921053 kWh/m3(N)
Relative density: 0.58868194743353996
Creating gas network object ...
Reading nodes file ...
Reading edges file ...
Reading stations file ...
Reading pcvs file ...
Reading transporters file ...
Creating problem object ...
Solving equation of state ...
delta 348.10448984277537
delta 85.593082378399984
delta 20.351931301889923
Close
España
(Spain)
-332389,5473250
Escala
1:7849719
Representar
EPSG:3857

Graphical User Interface

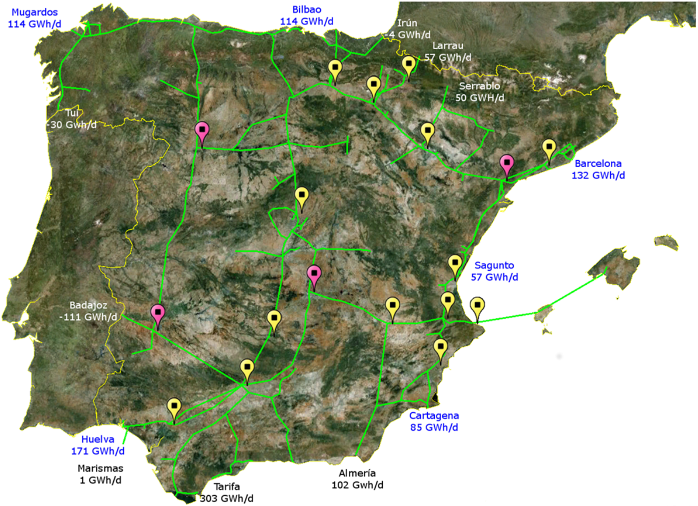
- The graphical user interface is based on a open source project called Quantum GIS.
- A specific plug-in was developed in order to interact with the kernel.
- It allows to employ on-line cartography services, such as Google Maps and Open Street Map, and off-line cartography.
- GANESO can read and write Microsoft Excel XML files. It can also write Google Earth files.

Optimization of the Spanish gas network

Optimization premises

- International connections and underground facilities are taken as fixed inputs.
- The optimizer has freedom to choose the distribution of flow among the regasification plants.
- The optimizer has freedom to choose how to use compressor stations, PCVs and FCVs.
- The cost function is based on the gas consumption in the compressor stations.
- Work day of January with low demand.

Usual management without optimization



Optimized management

Distribution of flow in the plants

[GWh/day]	No opt.	With opt.
Barcelona	131.8407	241.6383
Bilbao	113.8560	90.6997
Cartagena	85.3920	38.2229
Huelva	170.7840	83.6432
Reganosa	114.1571	106.4408
Sagunto	56.9280	112.3129

Before Vs After:

- From South = Cartagena + Huelva = -134.3099 GWh/d
- From North = Reganosa + Barcelona + Bilbao = +78.9250 GWh/d

Compression cost in the stations

[GWh/day]	No opt.	With opt.
Alcazar	0.2909	-
Algete	-	-
Almendralejo	0.2650	0.1587
Baneras	-	-
Chinchilla	-	-
Cordoba 1	-	-
Cordoba 2	-	-
Crevillente	-	-
Denia	-	-
Haro	-	-
Montesa	-	-
Navarra	-	-
Paterna	-	-
Puertollano	-	-
Sevilla	-	-
Tivisa	0.2229	-
V. Arnedo	-	-
Zamora	0.1516	-
Zaragoza	-	-
TOTAL	0.9304	0.1587

Remarks

- GANESO has optimized the distribution of flow among the regasification plants and the use of compressor stations.
- Based on this management, the cost could be up to 17 % of the usual one.
- It took 5-10 minutes on a desktop computer.

Conclusions

Conclusions

- We have developed new algorithms to optimize gas transport network problems, based on a two-stage procedure.
- In the first stage, based on Sequential Linear Programming techniques, an initial solution is obtained.
- Then, this initial solution is refined using a Control Theory approach.
- Furthermore, the above algorithms have been implemented in GANESO, which has proved useful for the company who funded this research.

Ongoing work

We are developing:

- A transient model for simulation and optimization.
- In order to help with the decision making regarding network expansions, we are enhancing GANESO with stochastic programming functionalities.
- A parallel computing version of GANESO.
- A system tariff module to analyze the guidelines of EU regarding the entry-exit tariffs.
- An additional module to compute the gas loss allocation.

TUSEN TAKK

Our financial supporters:

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NILS mobility project

ICELAND LIECHTENSTEIN NORWAY eea grants

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