MPNG

MATPOWER-Natural Gas

Users's Manual

Version 0.99a

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Contents

List of Figures

List of Tables

Introduction

1.1 Background

MPNG is a package of MATLAB [1,2] for solving optimal power and natural gas flow problems. MPNG uses the general user nonlinear constraints capability of MATPOWER to model the gas network taking into account: gas-fired power generators, storage units, wells, power-and-gas-driven compressors, and nodes with stratified demand (different market segments get different priorities). The MPNG source code can be found at:

https://github.com/MATPOWER/mpng.git

MPNG was developed by Sergio García-Marín [1] and Wilson González-Vanegas [2] under the direction of Carlos E. Murillo-Sánchez [1]. The initial need for a MATPOWER-based power and natural gas optimal flow package was born out of a project aimed to analyze the integrated operation of the Colombian power and natural gas systems.[3]

[1] Universidad Nacional de Colombia - sede Manizales

[2] Universidad Tecnológica de Pereira

[3] Project number 1110-745-58696, funded by Colciencias, Colombia.

Getting started

Here the getting started section goes...

Formulation

Nomenclature

Indexes

i, j	Gas nodes.
m, n	Electric nodes (buses).
o	Gas pipeline.
c	Compressor.
l	Transmission line.
w	Gas well.
e	Power generator.
ref	Reference bus.
r	Spinning reserve.
σ	Type of gas load.

Parameters

$\alpha^i_{\pi_+}, \alpha^i_{\pi_-}$	Penalties for over-pressure and under-pressure at node i.
α_γ	Penalties for non-supplied gas.
α_ϵ	Penalties for non-supplied electricity.
C^w_G	Gas cost at the well w.
C^{oij}_O	Transport cost of pipeline o, from node i to node j.

C_C^{cij}	Compression cost of compressor c, from node i to node j.
C_S^i	Storage cost at node i.
$C_{S_+}^i$	Storage outflow price at node i.
$C_{S_-}^i$	Storage inflow price at node i.
C_E^e	Power cost generation (excluding gas cost).
η_e^q	Thermal efficiency at generator q *[MMSCF/MW]*.
$D_g^{i\sigma}$	Gas demand of type σ at node i.
D_e^{tm}	Electricity demand in the bus m at time t.
$\bar{g}^w$, $\underline{g}^w$	Gas production limits.
$\overline{\pi}^i$, $\underline{\pi}^i$	Quadratic pressure limits at node i.
S_0^i	Initial stored gas at node i.
$\overline{S}^i$, $\underline{S}^i$	Storage limits at node i.
κ^{oij}	Weymouth constant of pipeline o.
δ^{oij}	Width for gas flow capacities.
β^{cij}	Compression ratio of compressor c.
Z^c	Ratio parameter of compressor c.
B^c	Compressor design parameter of compressor c.
x, y, z	Gas consumption parameters of gas-fired compressors.
$\overline{f}_g^{oij}$	Gas transport capacity of pipeline o, from node i to node j.
$\overline{f}_g^{cij}$	Gas flow capacity of compressor c, from node i to node j.
$\overline{f}_s^i, \underline{f}_s^i$	Storage outflow capacities at node i.
$\overline{p}_g^e$, $\underline{p}_g^e$	Active power generation limits of generator e.
$\overline{q}_g^e$, $\underline{q}_g^e$	Reactive power generation limits of generator e.
$\overline{V}^{tm} \underline{V}^{tm}$	Voltage limits for every bus m at time t.

$\mathbb{S}^l$	Transmission capacity of power line l.
R^{tr}	Spinning reserve in the r-th spinning reserve zone at time t.
M	Generators assignment matrix.
L	Compressors assignment matrix.
u^{te}	Unit commitment state for generator q at time t.
τ^t	Energy weight related to period of time t.
E^e	Available energy for hydroelectric generator e, during the total analysis window.

Sets

$\mathcal{N}$	Gas nodes, $\|\mathcal{N}\| = n_{\mathcal{N}}$.
$\mathcal{N}_{\mathcal{S}}$	Gas nodes with storage, $\mathcal{N}_{\mathcal{S}} \subset \mathcal{N}$, $\|\mathcal{N}_{\mathcal{S}}\| = n_{\mathcal{S}}$.
$\mathcal{O}$	Gas pipelines, $\|\mathcal{O}\| = n_{\mathcal{O}}$
$\mathcal{C}$	Compressors, $\|\mathcal{C}\| = n_{\mathcal{C}}$
$\mathcal{C}_G$	Compressors based on natural gas, $\mathcal{C}_G \subseteq \mathcal{C}$, $\|\mathcal{C}_G\| = n_{\mathcal{C}_G}$
$\mathcal{C}_E$	Compressors based on electric power, $\mathcal{C}_E \subseteq \mathcal{C}$, $\|\mathcal{C}_E\| = n_{\mathcal{C}_P}$
$\mathcal{W}$	Gas wells, $\|\mathcal{W}\| = n_{\mathcal{W}}$.
$\mathcal{W}^i$	Gas wells at node i, $\mathcal{W}^i \subset \mathcal{W}$, $\|\mathcal{W}^i\| = n_{\mathcal{W}^i}$.
$\mathcal{B}$	Power buses, $\|\mathcal{B}\| = n_{\mathcal{B}}$.
$\mathcal{L}$	Power lines, $\|\mathcal{L}\| = n_{\mathcal{L}}$.
$\mathcal{E}$	Power unit generators, $\|\mathcal{E}\| = n_{\mathcal{E}}$.
$\mathcal{E}_H$	Hydroelectric power units, $\mathcal{E}_H \subseteq \mathcal{E}$, $\|\mathcal{E}_H\| = n_{\mathcal{E}_H}$.
$\mathcal{E}_G^i$	Gas-fired power units connected to gas node i, $\mathcal{E}_G^i \subseteq \mathcal{E}$, $\|\mathcal{E}_G^i\| = n_{\mathcal{E}_G}$.
$\mathcal{Z}_r$	Spinning reserve zones.
$\mathcal{F}_G^i$, $\mathcal{T}_G^i$	Connected pipelines to node i at side *From* or *To*.

$\mathcal{F}_C^i$, $\mathcal{T}_C^i$ Connected compressors to node i at side *From* or *To*.

$\mathcal{F}_E^m$, $\mathcal{T}_E^m$ Connected power lines to bus m at side *From* or *To*.

$\mathcal{T}$ Total periods of analysis.

Σ Different types of gas loads.

Variables

f_g^{oij} Gas flow in pipeline o, from node i to node j.

f_{g+}^{oij} f_{g-}^{oij} Positive and negative gas flow in pipeline o.

f_g^{cij} Gas flow in compressor c, from node i to node j.

ψ^c Power consumed by compressor c.

ϕ^c Gas consumed by compressor c, connected to node i at side *From*.

$\gamma^{i\sigma}$ Non-served gas of type σ at node i.

π^i Quadratic pressure.

π_+^i, π_-^i Over/Under quadratic pressures at node i.

g^w Gas production at well w.

f_s^i Storage outflow difference.

f_{s+}^i, f_{s-}^i Storage outflow and inflow.

p_g^{te} Active power production at generator q at time t.

q_g^{te} Reactive power production at generator q at time t.

V^{tm} Voltage magnitude at bus m at time t.

θ^{tm} Voltage angle at bus m at time t.

ϵ^{tm} Non-served active power at bus m at time t.

We made a toolbox and we want to explain how it works.

3.1 Objective function

$$
\begin{aligned}
C\left(x\right) = & \sum_{w\in\mathcal{W}} C_G^w g^w + \sum_{t\in\mathcal{T}} \tau^t \sum_{e\in\mathcal{E}} C_E^e p_g^{te} \\
& + \sum_{i\in\mathcal{N}_S} \left(C_{S_+}^i f_{s_+}^i - C_{S_-}^i f_{s_-}^i\right) \\
& + \sum_{i\in\mathcal{N}_S} C_S^i \left(S_0^i - f_s^i\right) \\
& + \sum_{o\in\mathcal{O}} C_O^{oij} f_{g+}^{oij} - \sum_{o\in\mathcal{O}} C_O^{oij} f_{g-}^{oij} \\
& + \sum_{c\in\mathcal{C}} C_C^{cij} f_g^{cij} \\
& + \sum_{i\in\mathcal{N}} \alpha_{\pi_+}^i \pi_+^i + \sum_{i\in\mathcal{N}} \alpha_{\pi_-}^i \pi_-^i \\
& + \sum_{i\in\mathcal{N}} \sum_{\sigma\in\Sigma} \alpha_\gamma^{i\sigma} \gamma^{i\sigma} + \alpha_\epsilon \sum_{t\in\mathcal{T}} \tau^t \sum_{m\in\mathcal{B}} \epsilon^{tm}
\end{aligned} \tag{3.1}
$$

3.2 Constraints

3.2.1 Gas network

$$
\begin{aligned}
& \sum_{o\in\mathcal{T}_G^k} f_g^{oij} - \sum_{o\in\mathcal{F}_G^k} f_g^{oij} + \sum_{c\in\mathcal{T}_C^k} f_g^{cij} - \sum_{c\in\mathcal{F}_C^k} \left(f_g^{cij} + \phi^c\right) \\
& + \sum_{w\in\mathcal{W}^k} g^w + f_s^k - \sum_{t\in\mathcal{T}} \tau^t \sum_{e\in\mathcal{E}_G^k} \left(\eta_e^q \cdot p_g^{te}\right) = \sum_{\sigma\in\Sigma} \left(D_g^{\sigma k} - \gamma^{\sigma k}\right) \\
& \forall k \in \mathcal{N}
\end{aligned} \tag{3.2}
$$

The non-supply gas demand in every node of the system can only be as most as the total demand at the same node. This constraint is represented as follows:

$$
0 \leq \gamma^{\sigma k} \leq D_g^{\sigma k} \quad \forall \sigma \in \Sigma \quad \forall k \in \mathcal{N} \tag{3.3}
$$

Storage

$$
f_s^k = f_{s_+}^k - f_{s_-}^k \quad \forall k \in \mathcal{N} \tag{3.4}
$$

$$
\underline{f}_s^k \leq f_s^k \leq \overline{f}_s^k \quad \forall k \in \mathcal{N} \tag{3.5}
$$

$$
0 \leq f_{s_+}^i \leq S_0^k - \underline{S}^k \quad \forall k \in \mathcal{N} \tag{3.6}
$$

$$0 \leq f_{s_-}^{i} \leq \overline{S}^{k} - S_0^k \quad \forall k \in \mathcal{N} \tag{3.7}$$

Wells

The constraints related to the gas wells production depends on each well specific characteristics, these constraints are represented by:

$$\underline{g}^{w} \leq g^{w} \leq \overline{g}^{w} \quad \forall w \in \mathcal{W} \tag{3.8}$$

Pipelines:

$$f_g^{oij} = \kappa^{oij} sgn\left(\pi^i - \pi^j\right)\sqrt{\left|\pi^i - \pi^j\right|} \quad \forall o \in \mathcal{O} \tag{3.9}$$

And the gas flow limits for every pipeline:

$$f_g^{oij} = f_{g+}^{oij} + f_{g-}^{oij} \quad \forall o \in \mathcal{O} \tag{3.10}$$

$$-\overline{f}_g^{oij} \leq f_g^{oij} \leq \overline{f}_g^{oij} \quad \forall o \in \mathcal{O} \tag{3.11}$$

$$0 \leq f_{g+}^{oij} \leq \delta^{oij} \cdot \overline{f}_g^{oij} \quad \forall o \in \mathcal{O} \tag{3.12}$$

$$-\delta^{oij} \cdot \overline{f}_g^{oij} \leq f_{g-}^{oij} \leq 0 \quad \forall o \in \mathcal{O} \tag{3.13}$$

Compressors:

The power consumed by the compressors depend on its gas flow:

$$\psi^c = B^c f_g^{cij} \cdot \left(\left(\frac{\pi^j}{\pi^i}\right)^{Z^c/2} - 1\right) \quad \forall c \in \mathcal{C} \tag{3.14}$$

$$\phi^c = x + y\psi^c + z\psi^{c2} \quad \forall c \in \mathcal{C}_G \tag{3.15}$$

$$0 \leq f_g^{cij} \leq \overline{f}_g^{cij} \quad \forall c \in \mathcal{C} \tag{3.16}$$

$$\begin{array}{l} \pi^i \leq \pi^j \leq \beta^{cij}\pi^i \\ \beta^{cij} \geq 1 \end{array} \quad \forall i,j \in \mathcal{N} \quad \forall c \in \mathcal{C} \tag{3.17}$$

The equations 3.18 and 3.19 are the constraints that characterize the quadratic overpressure and underpressure at every node of the system, respectively.

$$\begin{array}{l} \pi^k \leq \overline{\pi}^k + \pi_+^k \\ 0 \leq \pi_+^k \end{array} \quad \forall k \in \mathcal{N} \tag{3.18}$$

$$\begin{aligned} &\underline{\pi}^k - \pi_-^k \le \pi^k \\ &0 \le \pi_-^k \end{aligned} \qquad \forall k \in \mathcal{N} \tag{3.19}$$

3.2.2 Power network

Equation 3.20 could be explained in an appendix section.

$$\begin{gathered} g_{p_m}\left(\theta^{tm}, V^{tm}, p_g^{te}, \epsilon^{te}, \psi^c\right) = 0 \\ g_{q_m}\left(\theta^{tm}, V^{tm}, q_g^{te}\right) = 0 \\ \forall m \in \mathcal{B} \quad \forall t \in \mathcal{T} \quad \forall c \in \mathcal{C}_E \end{gathered} \tag{3.20}$$

Variables limits:

$$\begin{aligned} &\theta^{tref} = 0 \\ &\underline{V}^{tm} \le V^{tm} \le \overline{V}^{tm} \end{aligned} \quad \forall m \in \mathcal{B} \quad \forall t \in \mathcal{T} \tag{3.21}$$

$$\begin{aligned} &\underline{p}_g^e \le p_g^{te} \le \overline{p}_g^e \\ &\underline{q}_g^e \le q_g^{te} \le \overline{q}_g^e \end{aligned} \quad \forall q \in \mathcal{E} \quad \forall t \in \mathcal{T} \tag{3.22}$$

Power flow limits:

$$\begin{aligned} &|\mathbb{S}_{fl}\left(\theta, V\right) \le \overline{\mathbb{S}}_{fl} \\ &|\mathbb{S}_{tl}\left(\theta, V\right)| \le \overline{\mathbb{S}}_{tl} \end{aligned} \quad \forall l \in \mathcal{L} \tag{3.23}$$

Non-supplied active power limits:

$$0 \le \epsilon^{tm} \le D_e^{tm} \quad \forall m \in \mathcal{B} \quad \forall t \in \mathcal{T} \tag{3.24}$$

Reserve constraint:

$$\begin{gathered} \textstyle\sum_{e \in \mathcal{Z}_r} u^{te}\left(\overline{p}_g^e - p_g^{te}\right) \ge R^{tr} \\ \forall r \in \mathcal{Z}_r \quad \forall t \in \mathcal{T} \end{gathered} \tag{3.25}$$

Hydro-energy constraint:

$$\sum_{t \in \mathcal{T}} \tau^t p_g^{te} \le E^e \quad \forall e \in \mathcal{E}_H \tag{3.26}$$

Examples

Here the examples section goes...

Bibliography

[1] R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, "Matpower: Steady-State Operations, Planning and Analysis Tools for Power Systems Research and Education," *Power Systems, IEEE Transactions on*, vol. 26, no. 1, pp. 12–19, Feb. 2011. doi: 10.1109/TPWRS.2010.2051168

[2] R. D. Zimmerman, C. E. Murillo-Sánchez (2019). Matpower [Software]. Available: `https://matpower.org` doi: 10.5281/zenodo.3236535