MP**N**G

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 MATPOWER-based [1, 2] package 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 forms part of the MATPOWER project and 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]

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[1] Universidad Nacional de Colombia - sede Manizales

[2] Universidad Tecnológica de Pereira

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

1

1.2   License and Terms of Use

Getting started

2.1 System Requirements

2.2 Getting `MPNG`

2.3 Running a Simulation

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

$\alpha_{\pi_+}^i, \alpha_{\pi_-}^i$	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_G^w	Gas cost at the well w.
C_O^{oij}	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.

$\bar{\pi}^i$, $\underline{\pi}^i$ Quadratic pressure limits at node i.

S_0^i Initial stored gas at node i.

$\bar{S}^i$, $\underline{S}^i$ 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.

$\bar{f}_g^{oij}$ Gas transport capacity of pipeline o, from node i to node j.

$\bar{f}_g^{cij}$ Gas flow capacity of compressor c, from node i to node j.

$\bar{f}_s^i$, $\underline{f}_s^i$ Storage outflow capacities at node i.

$\bar{p}_g^e$, $\underline{p}_g^e$ Active power generation limits of generator e.

$\bar{q}_g^e$, $\underline{q}_g^e$ Reactive power generation limits of generator e.

$\bar{V}^{tm}\underline{V}^{tm}$ 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, $\mathcal{C}_G \subseteq \mathcal{C}$, $\quad |\mathcal{C}_G| = n_{\mathcal{C}_G}$

$\mathcal{C}_E$ Compressors based on electric power, $\mathcal{C}_E \subseteq \mathcal{C}$, $\quad |\mathcal{C}_E| = n_{\mathcal{C}_P}$

$\mathcal{W}$ 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.

$\pi_+^i,\ \pi_-^i$ 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:

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

Storage

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

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

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

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

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:

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

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:

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

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

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

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

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

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

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

3.2.2 Power network

Equation 3.20 could be explained in an appendix section.

$$\begin{aligned} g_{p_m}\left(\theta^{tm}, V^{tm}, p_g^{te}, \epsilon^{te}, \psi^c\right) &= 0 \\ g_{q_m}\left(\theta^{tm}, V^{tm}, q_g^{te}\right) &= 0 \end{aligned} \tag{3.20}$$

$$\forall m \in \mathcal{B} \quad \forall t \in \mathcal{T} \quad \forall c \in \mathcal{C}_E$$

Variables limits:

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

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

Power flow limits:

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

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:

$$\sum_{e \in \mathcal{Z}_r} u^{te}\left(\overline{p}_g^e - p_g^{te}\right) \ge R^{tr}$$

$$\forall r \in \mathcal{Z}_r \quad \forall t \in \mathcal{T} \tag{3.25}$$

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

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