

MPNG

MATPOWER-Natural Gas

Users's Manual

Version 0.99a

Sergio García-Marín Wilson González-Vanegas Carlos E. Murillo-Sánchez

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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-Marín¹ and Wilson González-Vanegas² under the direction of Carlos E. Murillo-Sánchez¹. 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

¹Universidad Nacional de Colombia - sede Manizales

²Universidad Tecnológica de Pereira

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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}_S	Gas nodes with storage, $\mathcal{N}_S \subset \mathcal{N}$, $ \mathcal{N}_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}_E}$.
\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^i}$.
\mathcal{Z}_r	Spinning reserve zones.
$\mathcal{F}_G^i, \mathcal{T}_G^i$	Connected pipelines to node i at side <i>From</i> or <i>To</i> .

$\mathcal{F}_C^i, \mathcal{T}_C^i$	Connected compressors to node i at side <i>From</i> or <i>To</i> .
$\mathcal{F}_E^m, \mathcal{T}_E^m$	Connected power lines to bus m at side <i>From</i> or <i>To</i> .
\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 <i>From</i> .
$\gamma^{i\sigma}$	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

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

3.2 Constraints

3.2.1 Gas network

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

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

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

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

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

$$0 \leq f_{s-}^i \leq \bar{S}^k - S_0^k \quad \forall k \in \mathcal{N} \quad (3.7)$$

Wells

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

$$\underline{g}^w \leq g^w \leq \bar{g}^w \quad \forall w \in \mathcal{W} \quad (3.8)$$

Pipelines:

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

And the gas flow limits for every pipeline:

$$f_g^{oj} = f_{g+}^{oj} + f_{g-}^{oj} \quad \forall o \in \mathcal{O} \quad (3.10)$$

$$-\bar{f}_g^{oj} \leq f_g^{oj} \leq \bar{f}_g^{oj} \quad \forall o \in \mathcal{O} \quad (3.11)$$

$$0 \leq f_{g+}^{oj} \leq \delta^{oj} \cdot \bar{f}_g^{oj} \quad \forall o \in \mathcal{O} \quad (3.12)$$

$$-\delta^{oj} \cdot \bar{f}_g^{oj} \leq f_{g-}^{oj} \leq 0 \quad \forall o \in \mathcal{O} \quad (3.13)$$

Compressors:

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

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

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

$$0 \leq f_g^{cij} \leq \bar{f}_g^{cij} \quad \forall c \in \mathcal{C} \quad (3.16)$$

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

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

$$\begin{aligned} \pi^k &\leq \bar{\pi}^k + \pi_+^k \\ 0 &\leq \pi_+^k \end{aligned} \quad \forall k \in \mathcal{N} \quad (3.18)$$

$$\begin{aligned} \frac{\pi^k}{0} - \pi_-^k &\leq \pi^k \quad \forall k \in \mathcal{N} \end{aligned} \quad (3.19)$$

3.2.2 Power network

Equation 3.20 could be explained in an appendix section.

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

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

Variables limits:

$$\begin{aligned} \theta^{tref} &= 0 \\ \underline{V}^{tm} &\leq V^{tm} \leq \bar{V}^{tm} \quad \forall m \in \mathcal{B} \quad \forall t \in \mathcal{T} \end{aligned} \quad (3.21)$$

$$\begin{aligned} \underline{p}_g^e &\leq p_g^{te} \leq \bar{p}_g^e \\ \underline{q}_g^e &\leq q_g^{te} \leq \bar{q}_g^e \end{aligned} \quad \forall q \in \mathcal{E} \quad \forall t \in \mathcal{T} \quad (3.22)$$

Power flow limits:

$$\begin{aligned} |\mathbb{S}_{fl}(\theta, V)| &\leq \bar{\mathbb{S}}_{fl} \quad \forall l \in \mathcal{L} \\ |\mathbb{S}_{ul}(\theta, V)| &\leq \bar{\mathbb{S}}_{ul} \end{aligned} \quad (3.23)$$

Non-supplied active power limits:

$$0 \leq \epsilon^{tm} \leq D_e^{tm} \quad \forall m \in \mathcal{B} \quad \forall t \in \mathcal{T} \quad (3.24)$$

Reserve constraint:

$$\begin{aligned} \sum_{e \in \mathcal{Z}_r} u^{te} (\bar{p}_g^e - p_g^{te}) &\geq R^{tr} \\ \forall r \in \mathcal{Z}_r \quad \forall t \in \mathcal{T} \end{aligned} \quad (3.25)$$

Hydro-energy constraint:

$$\sum_{t \in \mathcal{T}} \tau^t p_g^{te} \leq E^e \quad \forall e \in \mathcal{E}_H \quad (3.26)$$

Examples

Here the examples section goes...

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