Optimization test of Interconnected Natural Gas and Power Systems Using Mathematical Programs with Complementarity Constraints

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Outline

Relevance of natural gas

Natural gas is an energy source that has acquired great relevance worldwide, and this can be attributed to two fundamental causes.

- It has been observed that a country's economic growth is closely related to its energy consumption.
- Natural gas emits less greenhouse gases compared to other fossil fuels, making it a favorable option for climate change mitigation.

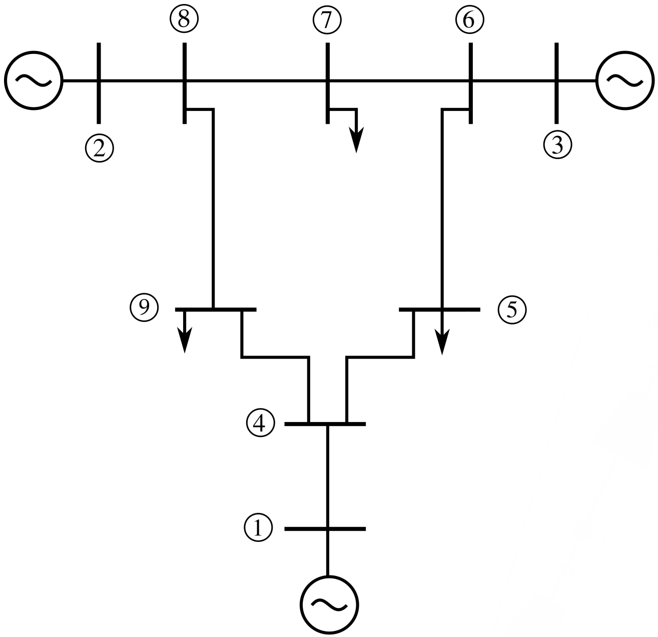
Global and national context

- Global natural gas consumption in 2015 reached 124.24 trillion cubic feet, with a projected increase of 43% by 2040, 75% of which is associated with the industrial sector and power generation from thermal plants.
- In the Colombian case, natural gas is a very important energy source because it is used in several sectors such as residential, commercial, industrial and thermal. It is especially in the latter where this fuel acquires greater relevance in dry seasons, since that is when the level of reservoirs is reduced and therefore also lowers the generation in hydroelectric plants.

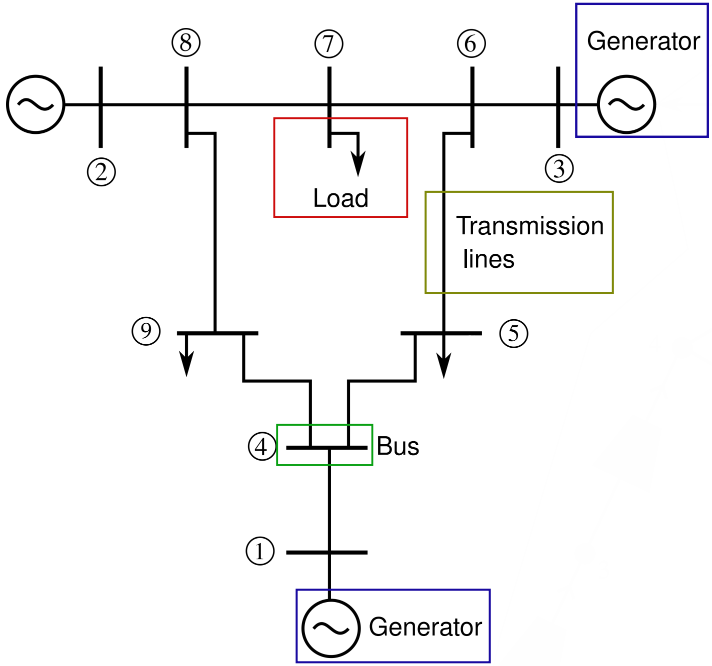
Challenges in the Colombian energy system

Although most of the country's electricity demand is commonly supplied by hydroelectric power plants, this type of generation presents an important source of uncertainty in the energy system, since its effectiveness and generation capacity are directly linked to the country's weather and climate conditions.

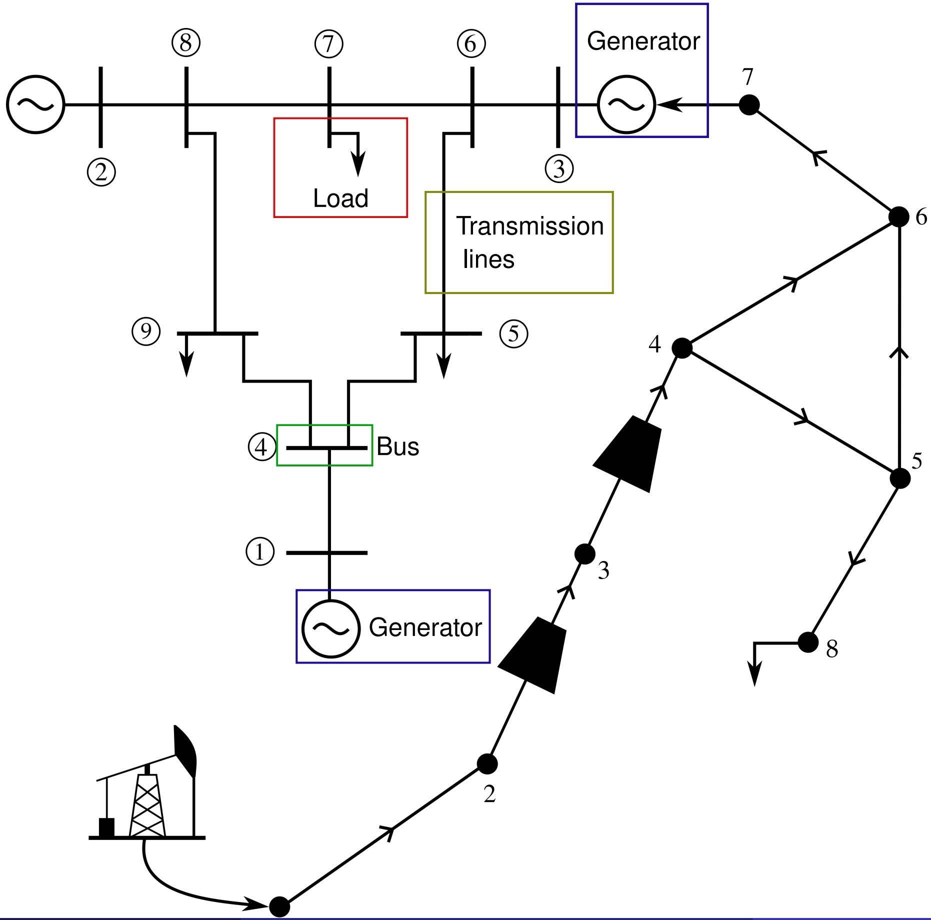
Problem statement



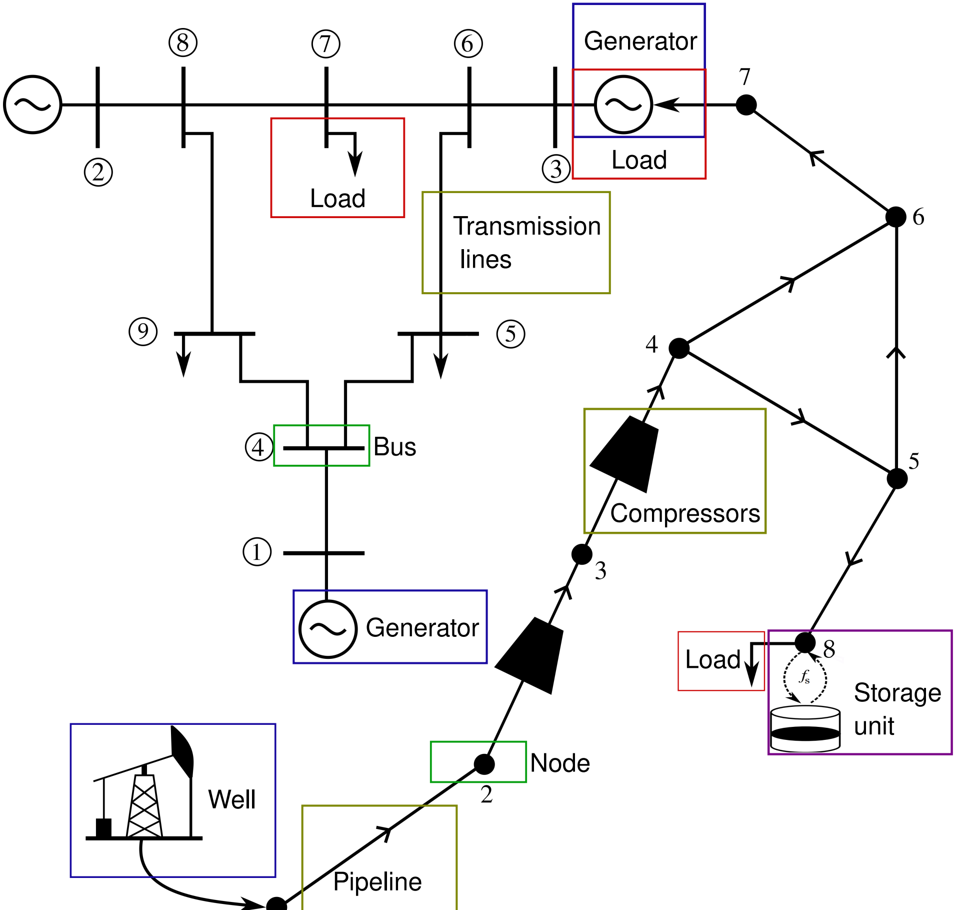
Power system



Interconnected system



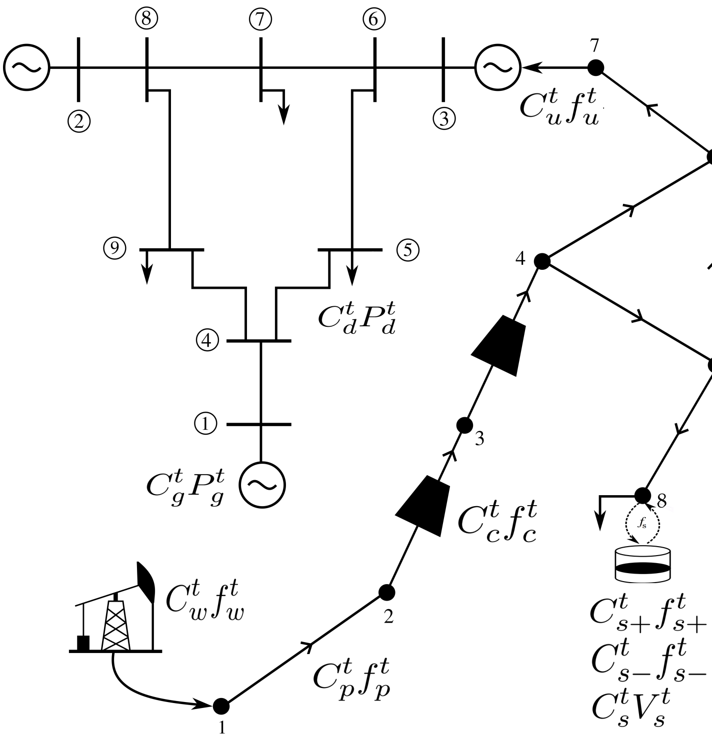
Interconnected System



Interconnected system - Definition

A power-gas interconnected system is a hybrid infrastructure that integrates natural gas and power networks, enhancing overall system efficiency [?]. Its key components include power generators, transmission lines, consumption buses, gas wells, pipelines, compressor stations, gas storage units, and consumption nodes.

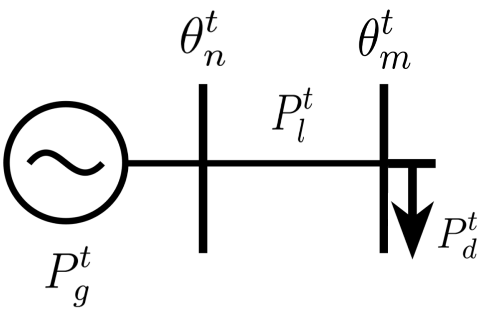
Objective function



$$
\begin{aligned}
\min_{\mathcal{P},\mathcal{F}} \quad & \sum_{g\in\mathcal{G}} C_g^t P_g^t + \sum_{d\in\mathcal{D}} C_d^t P_d^t + \\
& \sum_{w\in\mathcal{W}} C_w^t f_w^t + \sum_{p\in\mathcal{P}} C_p^t f_p^t + \\
& \sum_{c\in\mathcal{C}} C_c^t f_c^t + \sum_{u\in\mathcal{U}} C_u^t f_u^t + \\
& \sum_{s\in\mathcal{S}} C_{s+}^t f_{s+}^t + \sum_{s\in\mathcal{S}} C_{s-}^t f_{s-}^t + \\
& \sum_{s\in\mathcal{S}} C_s^t V_s^t
\end{aligned} \tag{1}
$$

Power system constraints

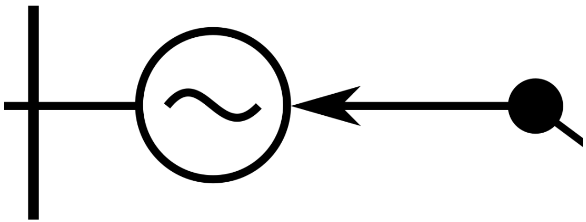
The constraints of the electrical system represent the technical limits of the different elements that compose it, as well as the physical laws that govern it. For certain applications, the DC model is sufficient [?].



$$
\begin{aligned}
\underline{P_g^t} \le P_g^t &\le \overline{P_g^t} && \forall\ g \in \mathcal{G}, && \text{(2a)}\\
-\overline{P_l^t} \le P_l^t &\le \overline{P_l^t} && \forall\ l \in \mathcal{L}, && \text{(2b)}\\
P_l^t &= B_{nm}(\theta_n - \theta_m) && \forall\ l = (n,m) \in \mathcal{L}, && \text{(2c)}\\
0 \le P_d^t &\le \overline{P_d^t} && \forall\ d \in \mathcal{D}, && \text{(2d)}\\
-\overline{\theta_n^t} \le \theta_m^t &\le \overline{\theta_n^t} && \forall\ n \in \mathcal{N}_P, && \text{(2e)}\\
\sum_{\substack{l \in \mathcal{L}_{n+}\\ g=n}} P_l^t + P_g^t &= \sum_{\substack{l \in \mathcal{L}_{n-}\\ d=n}} P_l^t + P_d^t && \forall\ n \in \mathcal{N}_P && \text{(2f)}
\end{aligned}
$$

Interconnection constraints

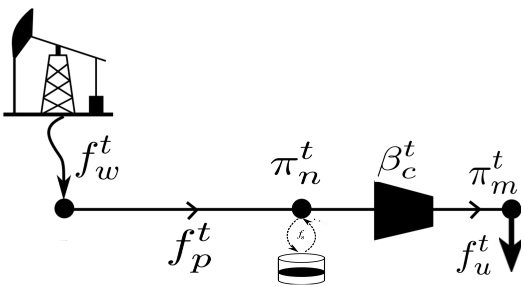
The second set of restrictions interconnects the natural gas and electric power systems through gas-fired power plants that generate electricity. f_n^t stands for the natural gas fuel consumption to generate a power P_n^t at generator bus $n \in \mathcal{N}_I$, the heat-rate HR_n defines the generator efficiency, and the set $\mathcal{N}_I = \mathcal{G} \cap \mathcal{U}$ holds all the units in the interconnected system belonging to both the power generator and gas demand sets.



$$f_n^t = P_n^t \cdot \mathrm{HR}_n, \quad \forall\, n \in \mathcal{N}_I, \tag{3}$$

Gas system constraints

This set of constraints ensures that wells, pipelines, nodal pressures, compressors, unsupplied demand and storage facilities operate within proper operating limits. [**?**].



$$\underline{f_w^t} \leq f_w^t \leq \overline{f_w^t} \quad \forall\ w \in \mathcal{W} \tag{4a}$$

$$-\overline{f_p^t} \leq f_p^t \leq \overline{f_p^t} \quad \forall\ p \in \mathcal{P} \tag{4b}$$

$$\underline{\pi_n^t} \leq \pi_n^t \leq \overline{\pi_n^t} \quad \forall\ n \in \mathcal{N}_f \tag{4c}$$

$$\pi_m^t \leq \beta_c^t \pi_n^t \quad \forall c = (n, m) \in \mathcal{C} \tag{4d}$$

$$0 \leq f_u^t \leq \overline{f_u^t} \quad \forall\ u \in \mathcal{U} \tag{4e}$$

$$0 \leq f_{s+}^t \leq V_{0s} - \underline{V_s} \quad \forall\ s \in \mathcal{S} \tag{4f}$$

$$0 \leq f_{s-}^t \leq \overline{V_s} - V_{0s} \quad \forall\ s \in \mathcal{S} \tag{4g}$$

$$V_s^t = V_s^{t-1} + f_{s-}^{t-1} - f_{s+}^{t-1} \quad \forall\ s \in \mathcal{S} \tag{4h}$$

(4i)

References I