Multistage stochastic optimization of an elementary hydrogen infrastructure

Lefgoum Raian[1,2], Pierre Carpentier[1], Jean-Philippe Chancelier[1], Michel De Lara[1]

[1] CERMICS, Ecole des Ponts, Marne-la-Vallée
{raian.lefgoum,jean-philippe.chancelier, michel.delara}@enpc.fr
pierre.carpentier@ensta-paris.fr
[2] Persee, Lyon, France
rnl@pers-ee.com

Mots-clés : *Stochastic optimization, Hydrogen infrastructure control, Dynamic programming.*

Hydrogen displays promising features for decarbonization industry, transportation and building sectors. The desired transition towards a hydrogen economy requires hydrogen costs to come down, through optimal choices of infrastructure design and operation. Most of the literature models hydrogen problems in a deterministic manner and solves them using linear programming [1, 2, 3]. In this talk, we present an approach based on multistage stochastic optimization, mixing design choices with operational decisions taken on an hourly basis.

We consider an elementary hydrogen infrastructure which consists of an electrolyzer, a compressor and a storage to serve a transportation demand. This infrastructure is powered by three sources of energy (on site photovoltaics, renewable electricity through power purchase agreement, power grid) with their own characteristics. The modelling of the electrolyzer covers its different functioning modes and the nonlinear relation between the production of hydrogen and the electricity consumption.

The optimization problem is to minimize the expected operational costs over a week by making hourly decisions in an uncertain context. This involves managing the electrolyzer's load and mode, quantifying the electricity supplied by each source, and determining the amount of hydrogen extracted from the storage to satisfy the demand. Renewable energy sources are emphasized in the hydrogen production process to ensure eligibility for a subsidy, which is awarded if the proportion of non-renewable electricity usage stays under a predetermined threshold. We consider uncertainties affecting on site photovoltaics production and hydrogen demand. All decisions are taken prior to the occurrence of uncertainties, except for the decision regarding the grid electricity supply, which is treated as a recourse following the realization of these uncertainties.

In this work, we formulate a multistage stochastic optimization problem, assuming stagewise independence of the noise. Building on this assumption, we develop decomposition algorithms based on dynamic programming. We present numerical results for a given infrastructure design. Then, we consider various combinations of infrastructure designs and their subsequent optimal operation. With this, we discuss the optimal sizing of equipment, especially the sensitivity of electrolyzer and storage designs to the uncertainties.

Finally, we give more details on the model describing the decision and state variables, the uncertainties, the objective function and briefly describing the constraints.

Decision variable	Description
$\mathbf{E}_h^{\mathrm{PPA}}$	Electricity from PPA contract (kWh)
$\mathbf{E}_{h+1}^{\mathrm{G}}$	Electricity from the grid (kWh)
$\mathbf{l}_h^{\mathrm{E}}$	Load at which the electrolyzer is functioning (%)
$\mathbf{M}_h^{\mathrm{E}\frown}$	Turn the electrolyzer to cold, idle or start mode
$\mathbf{H}_h^{\to\mathrm{D}}$	Quantity of hydrogen extracted from the storage (kg) to satisfy demand

TAB. 1 – Decision variables

State variable	Description
M_h^{E}	mode of the electrolyzer ($\{start, idle, cold\}$)
S_h	quantity of hydrogen in the storage (kg)
P_h	remaining stock of available PPA (kWh)
Q_h	"cumul of electricity"

TAB. 2 – State variables

Uncertainty	Description
$\mathbf{E}_{h+1}^{\mathrm{PV}}$	Renewable (PV) electricity (kWh) during $[h, h+1[$
$\mathbf{D}_{h+1}$	Demand of hydrogen (kg) during $[h, h+1[$

TAB. 3 – Uncertainties

The objective is to minimize the following cost

$$\min_{(\mathbf{E}_h^{\mathrm{PPA}}, \mathbf{E}_{h+1}^{\mathrm{G}}, \mathbf{M}_h^{\mathrm{E}\frown}, \mathbf{l}_h^{\mathrm{E}}, \mathbf{H}_h^{\to\mathrm{D}})_{h\in\mathbb{H}}} \mathbb{E}_{(\mathbf{D}_{h+1}, \mathbf{E}_{h+1}^{\mathrm{PV}})_{h\in\mathbb{H}}} \Big[\sum_{h\in\mathbb{H}} \underbrace{c^{ppa}\mathbf{E}_h^{\mathrm{PPA}}}_{\text{PPA cost}} + \underbrace{c_h^g \mathbf{E}_{h+1}^{\mathrm{G}}}_{\text{Grid cost}} + \underbrace{c^d(\mathbf{D}_{h+1} - \mathbf{H}_h^{\to\mathrm{D}})_+}_{\text{Demand dissatisfaction cost}} + \underbrace{K\big((\mathbf{E}_h^{\mathrm{PPA}}, \mathbf{E}_{h+1}^{\mathrm{G}}, \mathbf{E}_{h+1}^{\mathrm{PV}})_{h\in\mathbb{H}}\big)}_{\text{Final cost}} \Big]$$

subject to

— nonanticipativity constraints

— operational and renewable energy constraints

— state dynamics

— a coupling constraint between the energy mix and the hydrogen equipments

$$\underbrace{\mathbf{E}_h^{\mathrm{PPA}} + \mathbf{E}_{h+1}^{\mathrm{G}} + \mathbf{E}_{h+1}^{\mathrm{PV}}}_{\text{electricity supply}} = \underbrace{g(\mathbf{M}_h^{\mathrm{E}\frown}, \mathbf{M}_h^{\mathrm{E}}, \mathbf{l}_h^{\mathrm{E}})}_{\text{electricity consumption}} ,$$

Références

[1] A. Almansoori and A. Betancourt-Torcat. Design of optimization model for a hydrogen supply chain under emission constraints - a case study of germany. *Energy*, 111 :414–429, 2016.

[2] Manuel Tobias Baumhof, Enrica Raheli, Andrea Gloppen Johnsen, and Jalal Kazempour. Optimization of hybrid power plants : When is a detailed electrolyzer model necessary ? In *2023 IEEE Belgrade PowerTech*. IEEE, June 2023.

[3] Gonzalo Guillén-Gosálbez, Fernando Mele, and Ignacio Grossmann. A bi-criterion optimization approach for the design and planning of hydrogen supply chains for vehicle use. *AIChE Journal*, 56 :650 – 667, 09 2009.