Optimization of the electricity mix with high penetration of renewables : A robust method derived from Bayesian inference and graph theory

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1 Motivation

In this paper, I propose an original approach to robust optimization applied to the case of the design of an optimal electricity mix under strong penetration of renewables. This novel methodology, associated to a mixed-integer linear program (MILP) model of the electric generation system, is used to estimate the flexibility requirements and technical characteristics of future systems that allows to maintain supply-demand balance in the most extreme conditions. This article proposes original tools to define such "worst-case" conditions, applied to the concept of residual demand[1] sequences.

2 Methodology

Residual demand can be considered as a random process. For a process of given finite length and a set of observations (vectors of hourly wind speed within a day for instance), I approximate its joint probability distribution using a set of concurrent multivariate distributions and tools from Bayesian inference. For each concurrent model and possible path that can be taken by the random process, I associate a "local" Poisson distribution with parameter defined as a function of its probability of occurrence. Then, I can compute the minimum number of trials that is required for this path to be taken at least once by the random process.

This allows me to define the "$(\boldsymbol{\epsilon},\boldsymbol{M})$ certainty set", which corresponds to the set of paths for the random process which have a probability greater than $\mathbf{1}-\boldsymbol{\epsilon}$ to be observed at least once after $\boldsymbol{M}$ trials. This flexible concept allows us to restrict the set of trajectories taken by the random process to the subset of trajectories that appear at least once with probability greater than $\mathbf{1}-\boldsymbol{\epsilon}$ after $\boldsymbol{M}$ trials. This set restricts the space of potential residual demand trajectories that can be considered for optimal investment and design decision-making.

Then, using elementary matrix algebra and graph theory, I use the "$(\boldsymbol{\epsilon},\boldsymbol{M})$ certainty set" to derive in polynomial time a family of "worst-case" trajectories, including the most volatile path that can be generated by the random process. This involves the introduction of an original algorithm taking advantage of the complete graph structure of the possible paths. I apply this robust approach to an

[1] Residual demand is defined as electricity demand minus the production from renewable energy sources.

investment and dispatching model of the electric system of the French region Auvergne Rhône-Alpes, formulated as a MILP with commitment constraints.

3 Results

The methodology introduced in this paper allows the distinction of three types of “worst-case” trajectories for residual demand. For a trajectory of a given length, the first and second trajectories corresponds to the sequences of values where residual demand respectively take its highest or lowest possible values. The third trajectory corresponds is the most “chaotic” one, and corresponds to the sequence that maximizes the variations of residual demand.

These trajectories are used as input in the MILP model, which integrate unit-commitment and thermal constraints modeled using integer constraints. This approach allows the precise estimation of the optimal capacities and technology types associated to various flexibility and supply requirements. It is also used to measure the flexibility potential of nuclear as a load-following technology.