Optimization & Stability of Stochastic Unit-commitment Problems

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Abstract

This project deals with theoretical and numerical studies aiming at the improvement of unit-commitment problems subject to uncertainty. Unit-commitment refers to the operation of a physical system - the power mix - for which it is becoming more and more important to incorporate stochastic effects, due to the increased use of renewable energy sources. To tackle the issues that we want to address, we must deal with problems that are larger (because of the multiple options proposed by uncertainty) and more complex (because of complicated operational issues associated with intermittence). New techniques from variational analysis, data manipulation (big data), and computational mathematics are required to improve solution methods in this setting. In order to address effectively the complexity of unit-commitment problems, tools from several disciplines such as Variational Analysis, Stochastic Programming, and Computational Optimization need to be brought together.

Introduction

The unit-commitment problem in energy management aims at finding the optimal production schedule of a set of generation units while meeting various system-wide constraints. It has always been a large-scale, non-convex difficult problem, especially in view of the fact that operational requirements imply that it has to be solved in an semi-possibly small time (for its run). Recently, the ever increasing capacity for renewable generation has strongly increased the level of uncertainty in the system, making the (ideal) unit-commitment model a large-scale, non-convex, mixed (stochastic, robust, chance-constrained) program. Starting from this viewpoint, recently extensions such as a full large-scale two-stage unit-commitment problem have been investigated in [2]. However for practical reasons, the number of scenarios incorporated in an estimation of the recourse cost function tends to remain limited. This raises the question of stability of the estimated optimal value with respect to this limitation, and likewise the optimal solution. Another variant of the stochastic unit-commitment problem uses probabilistic constraints. In several situations the latter have been shown to be non-smooth, but differentiable in a generalized way. In these situations, the tools from variational analysis have been proven valuable to obtain a characterization of these problems and/or their solutions.

From theoretical viewpoint, we will investigate stability properties of the underlying optimization problems. From algorithmic viewpoint, we are interested in using computational power in the most economic way, while still assuring that we solve the original (say continuous) optimization problem.

Unit-commitment problems: a deterministic model

The optimal generation scheduling is an important daily activity for electric power generation companies. The goal is to determine which power units (hydro-plant, thermal-plant or nuclear-plant) are to be used in order to generate enough power to satisfy an electrical load, with minimum operating cost and reliability.

Figure 1: Different types of power units.

The time horizon of the schedule is, in general, one day. However, to avoid myopic decisions the optimization is performed over two days, even though only the first half of the schedule are actually sent to the local units. We symbolize a deterministic unit-commitment problem as

$$\min \sum_i c^i(p^i) \quad \text{s.t.} \quad \sum_i A^i(p^i) \ge d, \quad p_i \in \Omega^i, P_i$$

Denoting a power unit by i, the decision variable p_i stands for the operation planing of unit i, which lies in the feasible set of technical constraints P_i.

- Some of technical constraints defines discrete sets P_i;
- The operation planing of unit i has operation cost denoted by $c^i(p^i)$;
- Power generation of unit i is denoted by $A^i(p^i)$;
- Load demand and target reserves are represented by the vector d.

The constraint $\sum_i A^i(p^i) \ge d$ links the decision variables to take into account the satisfaction of the load demand (balance equations, and reserves to satisfy unexpected events.

Uncertainty Modelling

Up to a few years ago, the main sources of uncertainty in electrical systems were almost completely due to variation of users, demand and occurrence of faults. The former can efficiently be forecasted and the latter is traditionally taken into account by requiring some amount of spinning reserve, [1]. Recently, a relevant tendency in power systems is the ever increasing use of renewable production sources such as wind, hydro and solar power. Not surprisingly, this has significantly increased the underlying uncertainty in the system. Ignoring such a substantial increase in uncertainty levels generally leads to more expensive, and sometimes infeasible, production planning decisions. However, incorporating the uncertainty in the models is very challenging, in particular in view of the complexity of the deterministic versions of unit-commitment problems.

The two-main approaches that will be addressed in the PGMO project for dealing with uncertainty in unit-commitment problems are:

- stochastic optimization with recourse - scenario tree;
- optimization with probability constraint - chance-constrained programming.

Stochastic optimization with recourse:

In this approach, the uncertainty represented by ζ is incorporated in the problem as follows:

$$\min \ \mathbb{E}\left[\sum_i c^i(p^i)\right] \quad \text{s.t.} \quad \sum_i A^i(p^i) \ge d(\zeta), \quad p(\zeta) \in \Omega^i, P_i.$$

With this token, the planing strategy $p(\zeta)$ becomes a function of the random vector ζ. The objective function becomes the expected value of production cost, where $\mathbb{E}[\cdot]$ represents the expected value operator with respect to the probability measure ruling the random vector ζ. For practical purposes, ζ must be discretized in finitely many scenarios $\Omega \zeta_1, \ldots, \zeta_N$ with associated probabilities π_j, $j = 1, \ldots, N$. This leads to a scenario tree, as illustrated by Figure 2.
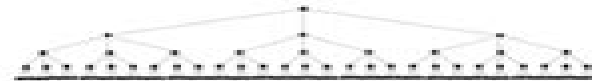

Figure 2: Scenario tree - each branch of the tree corresponds to a scenario ζ_j in (2).

Once these scenarios are available, problem (2) is approximated by

$$\min \sum_j \pi_j \left[\sum_i c^i(p^i)\right] \quad \text{s.t.} \quad \sum_i A^i(p^i) \ge d(\zeta_j), \quad p_i \in \Omega^i, P_i.$$

For the sake of precision, the above model needs a large number N of scenarios ζ_j to represent accurately the uncertainty. However, if the number of scenarios is too big, the optimization planning problem may be too difficult, if not impossible, to solve. This justifies the two axis of the project.

1. Variational analysis and stability. The practical relevance of the stability results resides in the fact that they provide theoretical backing that the obtained solutions remain reasonable for problems with adjacent data.
2. Algorithms. The second axis of the work deals with gradually incorporating (part of) the data/scenarios. Assuming a (generalized) Benders type of framework, it seems unreasonable to use knowledge of all scenarios for all iterations of the Benders master problem.

Chance-constrained programming

Another important strategy for dealing with uncertainty in unit-commitment problems is chance-constrained programming. This approach leads to the following (generic) formulation of unit-commitment problems with probabilistic constraints

$$\min \sum_i c^i(p^i) \quad \text{s.t.} \quad \mathbb{P}\left[\sum_i A^i(p^i) \ge d(\zeta)\right] \ge \alpha, \quad p_i \in \Omega^i, P_i.$$

where $\mathbb{P}$ is the probability measure associated to ζ. The probabilistic constraint $\mathbb{P}[\sum_i A^i(p^i) \ge d(\zeta)] \ge \alpha$ is means that we wish that the random inequality $\sum_i A^i(p^i) \ge d(\zeta)$ hold with high enough probability $\alpha \in (0, 1)$.

An important application of the work in the first axis to problems in the second axis is the investigation of stability for optimization problems under this (dynamic) probabilistic constraint. In fact, it turns out that the fundamental concepts of variational analysis such as metric regularity or calmness of multifunctions, particularly subdifferential, tangential/normal cone, and co-derivative mappings play a key role in stability investigations, [3].

It is worth mentioning that a particular interest of chance constraints for modelling unit-commitment problems has to do with cascaded reservoir management; see Figure 3 and[4].

Figure 3: A cascaded reservoir.

The joint chance constraint arises since we wish to make sure that the volumes in the reservoirs remain within bounds with high enough probability. The volumes are impacted by random inflows and turbining strategy.

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**Alexander P. Seyranian,Isaac
Elishakoff**

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