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ScienceDirect
European Journal of Operational Research 181 (2007) 1245–1264
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
www.elsevier.com/locate/ejor

A heuristic for the long-term electricity generation planning problem using the Bloom and Gallant formulation [☆]

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Received 1 November 2004; accepted 1 October 2005
Available online 15 May 2006

Abstract

Long-term power planning is a stochastic problem often confronted by electrical utilities in liberalized markets. One can model it for profit maximization—using market-price estimation functions for each interval—by posing it as a quadratic programming problem with some linear equalities and an exponential number of load-matching linear inequality constraints.

In order to avoid handling all the inequalities when one is attempting to solve the problem, column generation methods have been employed herein. In this paper, we describe the foundations and implementation of a heuristic that tries to iteratively guess the active set of constraints at the optimizer, alongside a normal quadratic programming solution used at each iteration. The two methods are compared and the heuristic procedure is shown to be more efficient.

Keywords: Energy; Heuristics; Large scale optimization; Quadratic programming; Stochastic programming

1. Introduction and motivation

Long-term energy generation planning is an issue of key importance to the operation of electricity generation companies. It is used to budget for and plan fuel acquisitions and to provide a framework for short-term energy generation planning.

The long-term problem is a well-known stochastic optimization problem, as several of its parameters are only known as probability distributions, such as load, the availability of thermal units, hydrogeneration and energy generations from renewable sources in general.

A long-term planning *period* (e.g., a natural year) is normally subdivided into shorter *intervals* (e.g., weeks or months), for which parameters (e.g., the load–duration curve) must be predicted, and variables (e.g., the expected energy productions of each generator unit) must be optimized. The load–duration curves (LDC's)

[☆] Partially supported by MCYT Grant DPI 2002-03330 of Ministerio de Ciencia y Tecnología, Spain.

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doi:10.1016/j.ejor.2005.10.070

predicted for each interval, which are equivalent to load-survival functions, are used as data for the problem, which is appropriate since load uncertainty can be suitably described using the LDC. It is assumed that the probability of failure for each thermal unit is known.

Bloom and Gallant [2] proposed a linear model (with an exponential number of inequality constraints) and used an *active set* methodology [8] to find the optimal way of matching the LDC of a single interval using thermal units, in the presence of load-matching and other operational non-load-matching constraints. These might be limits on the availability of certain fuels or on emissions. The number of load-matching constraints $(lmc) n_i \times 2^{n_u}$ is exponential to the number of units n_u for each of the n_i intervals considered in the problem, and gets to be very large even in moderately sized problems.

When a long-term power planning problem needs to be solved for a generation company operating in a liberalized market, the company does not have a load of its own to satisfy, but rather bids the energies produced by its units to a *market operator*, which selects the lowest-priced energy to match the load from amongst the units of bidding companies. In this case, the scope of the problem is no longer that of the generation units of a single generation company, but that of all the units of all companies bidding in the same competitive market, which matches the load of the whole system. This entails planning problems that are much larger than before and it is a reason for developing more efficient codes for solving them.

The Bloom and Gallant model has been successfully extended to multi-interval long-term planning problems, using either the active-set method [10], the Dantzig–Wolfe column generation method [5,15] or the Ford–Fulkerson column-generation method [6,13]. A quadratic model for formulating the long-term profit maximization of generation companies in a liberalized market has been proposed [11] and column generation procedures have been employed to solve it [14,12]. However, to apply quadratic programming (QP) or interior-point quadratic programming (IPQP) directly is not practical, even in moderately sized problems, due to the exponential number of linear inequalities. This paper puts forward a heuristic for building up the optimal active set of inequality *lmc*s. It employs a reduced subset of *lmc*s, which is enlarged in successive steps until the optimal active set and solution are found. Since the QP subproblems at each step of the heuristic have a moderate number of inequalities, plain QP or IPQP solvers can be employed instead of specialized column generation algorithms.

The paper is organized as follows: Section 2 describes the problem; Section 3 describes the Bloom and Gallant formulation and the solution methods employed so far; Section 4 introduces the proposed heuristic; Section 5 details how to check the feasibility of a solution; and the computational results and the conclusions follow in Sections 6 and 7.

2. The long-term electricity generation planning problem

2.1. The LDC

The LDC is the most sensitive technique for representing the load of a future interval. The main features of an LDC can be described using five characteristics: the duration t, the peak load power $\hat{p}$, the base load power $\underline{p}$, the total energy $\hat{e}$ and the shape, which is not a single parameter and is usually described using a table of durations and powers, or using a function.

The LDC for future intervals must be predicted. For a past interval, for which the hourly load record is available, the LDC is equivalent to the load–over-time curve sorted in order of decreasing power. It should be noted that in a *predicted* LDC, random events such as weather or shifts in consumption timing, which cause modifications of different signs in the load tend to cancel out, and that the LDC maintains the power variability of the load in its entirety.

2.2. Unavailability of units and the convolution method

As far as loading an LDC is concerned, the relevant parameters of a thermal unit are the power capacity c_j for the jth unit (the maximum power output in MW that the unit can generate), the outage probability q_j for the jth unit (the probability of the unit not being available when it is required for generating power) and a linear generation cost $\tilde{v}_j$ for the jth unit (the production cost in €/MW h).