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O.R. Applications

A variant of the dynamic programming algorithm for unit commitment of combined heat and power systems

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Abstract

The paper addresses the unit commitment in multi-period combined heat and power (CHP) production planning under the deregulated power market. In CHP plants (units), generation of heat and power follows joint characteristics, which means that production planning must be done in coordination. We introduce in this paper the DP-RSC1 algorithm, which is a variant of the dynamic programming (DP) algorithm based on linear *relaxation* of the ON/OFF states of the units and *sequential commitment* of units *one by one*. The time complexity of DP-RSC1 is proportional to the number of generating units in the system, the number of periods over the planning horizon and the time for solving a single-period economic dispatch problem. We have compared the DP-RSC1 algorithm with realistic power plants against the unit decommitment algorithm and the traditional priority listing method. The results show that the DP-RSC1 algorithm gives somewhat more accurate results (0.08–0.5% on average, maximum 10% for the individual sub-case) and executes 3–5 times faster on average than the unit decommitment algorithm. It is not surprising that the solution quality of the DP-RSC1 algorithm is much better than that of the priority listing method.

Keywords: Dynamic programming; Combined heat and power production; Unit commitment; Energy optimization; Deregulated power market

1. Introduction

Combined heat and power (CHP) production means the simultaneous production of useful heat and electric power. When steam or hot water is produced for an industrial plant or a residential area, power can be produced as a by-product. Vice versa, surplus heat from an electric power plant can be used for industrial

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purposes, or for heating space and water. CHP is considered an environmentally beneficial technology because of its high energy efficiency when compared to conventional condensing power plants.

Unit commitment (UC) is an important sub-problem in energy production planning. The goal in UC is to determine when to start up and shut down the plants (units) and how to dispatch the committed units to meet (forecast) demand and other constraints cost-efficiently. Under the deregulated power market, we also consider the possibility to buy and sell electric power on the spot market.

Different methods for solving UC problems have been reviewed by Sen and Kothari (1998) and Padhy (2004). Most of literature addresses the UC for power-only generation systems. Some methods such as Lagrangian relaxation (LR) (Thorin et al., 2005), Branch and Bound (BB) (Illerhaus and Verstege, 1999), and genetic algorithms (Sakawa et al., 2002) have been applied also to CHP systems.

Dynamic programming (DP) can in principle be used also for solving UC of CHP systems. The advantage of DP is its ability to maintain solution feasibility. The disadvantage is the "curse of dimensionality", which may result in unacceptable solution time. The dimension of the problem increases exponentially with the number of generating units. For power-only generation systems, the most widely used method to reduce the dimension is based on a priority list. The list is typically formed by ranking the units based on their marginal power production cost (MPPC) or average full load cost index (Sen and Kothari, 1998). These variants of DP algorithms include DP-SC (dynamic programming-sequential combination), DP-TC (dynamic programming-truncated combination), DP-STC (the combination of DP-SC and DP-TC approaches) and DP-VW (variable window-truncated dynamic programming) (Sen and Kothari, 1998 and Padhy, 2004).

However, these approaches are difficult to apply for CHP systems because CHP plants cannot be ranked as easily as power-only generation plants. The dependency of the power and heat generation in CHP plants makes the determination of MPPC and marginal heat production cost (MHPC) depend on both power and heat generation.

To reduce the dimension of the CHP UC problem in DP-based algorithms, Hakonen (1996) introduced a general DP scheme based on relaxed ON/OFF states of plants and sequential commitment of subsets of plants. We call this scheme the relaxation and sequential commitment (DP-RSC) algorithm. Relaxed state is a third state besides normal ON- and OFF-states. When a plant is at the relaxed state, it is allowed to operate continuously in the area between ON- and OFF-states. This means that the ON/OFF state variable can be temporarily excluded from the set of variables. We can thus reduce the dimension of the UC problem by setting temporarily some plants to the relaxed states and consider the ON/OFF combinations of fewer plants simultaneously. The ON/OFF states of the relaxed plants can then be determined sequentially based on some scheme. The additional benefit of the relaxed state is that the state-relaxed (SR) problem where all of the plants are at relaxed states (except forced OFF- or ON-hours) can provide a reasonable setting to rank plants.

Here we implement a special variant of the DP-RSC algorithm for solving UC in CHP production planning, called DP-RSC1. Initially, all plants are relaxed for all hours (except forced OFF- or ON-hours) in the planning horizon. Then, based on a predetermined plant sequence, the ON/OFF states of each plant over the entire planning horizon are determined based on DP, one-at-a-time, while the other plants remain at their relaxed or already determined ON/OFF states. The plant sequence has effect on the solution quality. The time complexity of DP-RSC1 is proportional to the number of generating units in the system, the number of periods over the planning horizon and the time for solving a single-period economic dispatch problem. To reduce the solution time, we shut down some less cost-efficient plants heuristically beforehand based on the solution to the SR problem.

DP-RSC1 is similar to the dual algorithm of the generic unit decommitment (UD) algorithm (Tseng et al., 1997) but it is more efficient. The UD algorithm starts with a unit commitment schedule where all available plants are at ON states (except forced OFF-hours) for the entire planning horizon and improves the schedule gradually by decommitting units, one-at-a-time based on DP. If the plant characteristics are convex, the time complexity of the generic UD is proportional to the square of the number of generating units in the system, the number of periods over the planning horizon and the time for solving a single-period economic dispatch problem. For power-only generation systems, Tseng et al. (1997) proposed two efficient versions of the UD algorithm utilizing MPPC of the plants. However, these versions of algorithms are difficult to apply for CHP systems, because the CHP plants cannot be ranked in the similar way as the power-only generation plants.