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Distributed Optimization of Energy Portfolio and Production Planning for Multiple Companies Under Resource Constraints

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Abstract

In this paper, we propose a distributed optimization approach to energy portfolio and production planning for multiple companies. The production planning problem for multiple companies with the selection of electricity procurement contracts under energy resource constraints is formulated as a mixed integer nonlinear programming problem. A Lagrangian decomposition and coordination technique is applied to solve the problem. The original problem is decomposed into several subproblems. Heuristics are applied to generate a feasible solution. Computational results show the proposed method can solve the problem effectively within a reasonable computation time.

Keywords: Energy optimization; Production planning; Distributed optimization technique

1. Introduction

With rapid progress in market liberalization of electrical power, a number of global manufacturing sites are trying to integrate their enterprises with other organizations by optimizing production planning for multiple companies. Japan has now severe electricity problems due to limitation of nuclear power resources. The use of renewable resources including geothermal energy, biomass, small hydro, wind and solar will increase in the next few years. Energy portfolio selection is the decision making of the selection of the use of such electricity sources or contracts considering spot market of electricity prices. Under the severe energy and resource situation, in order to reduce energy consumption and environmental burden, manufacturing plants are required to create production planning as well as energy portfolio taking into account of competitiveness in the market.

Such coordination has been executed in empirical ways by communication among production planning managers. However, planning decisions for each company are becoming increasingly complicated with an increasing number of alternative plans for a number of partner companies [1]. This makes it difficult to coordinate multiple companies for energy portfolio and production planning. A typical approach is a discrete event simulation combined with optimization methods. Conventional planning systems have been configured to obtain near-optimal plans incorporating an information sharing strategy for the overall companies using detailed information such as unit revenue, production cost, inventory holding cost, etc. for each company. However, in practice, such information is considered to be confidential for competing companies. Due to the confidentially reason, a distributed optimization system with partial information sharing is preferable [2].

A number of studies have been reported for electricity contract decision making problems [3][4]. Conventionally, electrical energy management problems have been discussed with hydrothermal plants [5], or unit commitment problems [6]. However, few studies have been reported for the production planning problem

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with electricity contracts. An energy portfolio and production planning for a single manufacturing plant has been studied [7]. The energy procurement portfolio and production planning problem is formulated as a mixed integer nonlinear programming problem. However, multi plants coordination problems have not been studied in previous works.

In this paper, we propose a distributed optimization approach to energy portfolio and production planning problems for multiple companies under resource constraints with partial information sharing. The problem for multiple companies is formulated as mixed integer programming problems. A Lagrangian relaxation method is applied to decompose the overall problem by relaxing interconnection constraints. Computational experiments demonstrate that the proposed method can create near-optimal solutions with less duality gap compared with conventional methods, even though only local information is used to derive a solution for each company.

The paper is organized as the following sections. Section 2 describes the problem definition and formulation of energy portfolio and production planning problems for multiple companies. Section 3 explains the decomposition approach for solving the problem by Lagrangian decomposition and coordination technique. Section 4 provides the computational results of a case study. Section 5 states the summary and conclusions with our future works.

2. Energy portfolio and production planning problem for multiple companies

2.1. Problem description

Consider an industrial complex where several companies share a common energy source. The total energy resource is restricted by maximum energy use for the companies at the industrial complex. Each company has to create collaborative production planning with selection of energy contracts.

In our problem setting, the following points are considered.

- A single site, multiple manufacturing plants with multiple companies, and a single product requiring one type of energy
- All parameters are known in advance as a deterministic case
- Each plant has an energy storage system

The constraints for energy use in each company are as follows.

(i) Constant-based contract: energy cost is proportional to its amount.

(ii) Time-based contract: energy cost depends on its time.

Unit costs for peak time periods e.g. AM9:00-PM13:00 and PM17:00-PM21:00 is higher than that of off-peak time periods.

(iii) Quantity-based contract: energy cost depends on its quantity purchased.

(iv) Spot-market contract: energy cost depends on its spot-market.

Each company can select every contract for energy use in each time period. The total energy cost consists of basic charge and the energy cost based on the selected contract. Energy portfolio and production planning problem treated in this study asks to find an optimal production quantity and inventories to minimize the total costs including total energy procurement costs, production costs, inventory holding costs and setup costs for multiple companies.

2.2. Problem formulation

The overall production planning problem is formulated as a mixed integer nonlinear programming problem in this section.

We use the following notation.

Sets and indices

$c \in C$: company

$t \in T$: time periods

T_1 : set of peak time periods

T_2 : set of off-peak time periods

$d \in D$: day

$a \in A = \{af, at, aq, as\}$ indicates contract selection, af is ratio-based, at is time-based, aq is quantity-based, and as is spot-based constraint

Parameters

U_d^c : demand in day d for company c

s^c : setup cost for company c

h^c : inventory holding cost for company c

$P_{d,t}^{\max}$: total energy consumption at time t in day d

r_f : unit energy cost for ratio-based contract

r_{b1}, r_{b2} : unit energy cost of peak and off-peak time for time-based contract

r_{q1}, r_{q2} : unit energy cost of peak and off-peak time for quantity-based contract

r_s : unit energy cost for spot market contract

var : risk sensitive coefficient

$Cov_{d,[T,T]}$: covariance matrix for day d