AUTOMATIC CONTROL SYSTEMS

About Control of Electricity Market

V. A. Kazakov,* A. M. Tsirlin,** and A. A. Ahremenkov**

*University of Technology, Sydney, Australia
**Program Systems Institute, Russian Academy of Sciences, Pereslavl-Zalesskii, Russia

Received January 30, 2009

Abstract—We consider auction problem for network of inter-connected energy markets. The conditions of optimality for this problem are derived. The numerical method based on these conditions for running auction is constructed. It is shown how running auction can be achieved by using automated control system.

PACS numbers: 02.30.Yy, 89.20.-a
DOI: 10.1134/S0005117909100099

1. INTRODUCTION

We consider electricity market which includes a fixed number of regional market linked by inter-regional connectors. Each market participant (generator or consumer) belongs to one of regional markets. All market participants pay/receive the same single regional price. As a rule regional prices in different regions are different.

Trading day is divided into a sequence of equal-length periods. During each of these periods “single period auction” is run. This single-period auction includes inter-linked auctions in all regional markets that are run simultaneously. Results of the auction depend on generators’ price-volume bids, state of the market before the auction (regional generations and inter-regional flows) and regional demands. Auction results determine dispatch (the amount of energy generated) by each producer in every regional market, all inter-regional flows and regional prices for the current period.

All generator submit their price bids (“price-volume bids”) before the auction. These bids are step-wise, non-decreasing functions showing the dependence of the price of the energy on the amount of energy supplied (Fig. 1). Price-steps in these bids can be (and often in fact are) negative. This means that rather than stopping generators producer pays consumer to use its energy.

Single-period auction consists of single-price regional auctions. That is, every generator trading in the same region gets the same price. Energy market is an oligopoly, where participants’ bids determine dispatch and prices. It is assumed that demand is independent of price (price elasticity of demand is zero). Generators submit price-volume bids for all single auction periods of the next trading day before it starts. The number of steps in the bid is constrained (in Australian market number of steps can not exceed 10 [1, 2]). Further constraints on the bids can also be imposed.

Regional dispatches and prices are determined not only by demand and generators’ price-volume bids. They also depend on how much energy is transferred between regional markets via inter-regional connectors, on the losses in these connectors and on constraints on the capacity of connectors to transfer energy. The aim of a single period auction is to find such generators’ dispatch that all demands are satisfied and the cost of generation is minimal. We will consider this problem in the paper.

1 This work was supported by the Russian Foundation for Basic Research, project no. 08-06-00-141a.
Economic dispatch problem for electricity has been the focus of numerous studies both academic and applied (see [3, 4]). As a rule these classic studies assume that the cost of generation (the objective function) is a continuous and continuously differentiable function. The solution obtained in this paper takes into account the special form the cost of generation takes when step-wise price-volume bids are used and the non-convexity of the problem due to negative prices that can be offered by generators.

The model used in this paper is very simple. In particular it is assumed that the energy flows are scalars. It also assumes that energy losses can be described by a simple parametric non-symmetrical function, whose parameters are fitted to the data periodically. However this model describes the market accurately enough to enable its efficient control. Most of the energy markets now are controlled using similar models. As a rule the auction problem based on this model is then linearized reducing it to the linear programming problem which is then solved using specialized linear programming algorithms [1, 2]. Gradients’ discontinuities and problems non-convexity can significantly reduce the efficiency of these methods. They can also stack in local minimal increasing the cost of generation unnecessarily.

In this paper we construct the algorithm for solving the multi-regional auction problem which overcomes the problem of discontines gradients and which finds the global solution of a non-convex problem. We start by stating mathematical model for the auction problem. We obtain the necessary conditions of optimality for it and construct numerical algorithm for solving these conditions. We then derive the sufficient conditions of optimality and show how they can be used to construct a bound on the global solution. Finally we show how to construct a feed-back control system to solves auction problem automatically.

2. SINGLE PERIOD AUCTION. OPTIMAL DISPATCH PROBLEM.

2.1. Problem Formulation

We consider network of n inter-connected regional energy markets (Fig. 2). At the beginning of each single-auction period market operator receives the following information:

1. Combined demand for electricity in every regional market \( d_i, i = 1, \ldots, n \);
2. Combined price-volume bid by all regional generators \( P_i(q_i) \);
3. Regional generations (dispatches) during the previous single auction period \( q_i(0) \);
4. Inter-regional flows during previous single auction period \( g_{ij}(0) \).

(Combined) regional price-volume bid is defined as the dependence of price \( P_i \) on the combined amount of energy offered by all generators in the region at a price not exceeding \( P_i \). Thus

\[
q_i = \sum_{\gamma = G_i}^{\gamma = G_i} \Delta_t \gamma, \quad \Delta_t \gamma = \max \Delta / P_t(\Delta) \leq P_t. \tag{1}
\]