Electric Power Systems Research 80 (2010) 537–546

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Electricity market equilibrium of nonlinear power systems with reactive power control

A.G. Petoussis[a], X.-P. Zhang[b,*], S.G. Petoussis[c], K.R. Godfrey[a]

[a] School of Engineering, University of Warwick, Coventry, CV4 7AL, UK
[b] Department of Electronic, Electrical and Computer Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK
[c] Electricity Authority of Cyprus (EAC), Nicosia, CY-1399, Cyprus

A R T I C L E I N F O

Article history:
Received 19 December 2007
Received in revised form
10 September 2009
Accepted 24 October 2009
Available online 6 December 2009

Keywords:
AC network modeling
Electricity market equilibrium
Market power
Nodal prices
Reactive power control
Supply function equilibrium

A B S T R A C T

The impact of reactive power control on the electricity market equilibrium is investigated. The effects of limitations on the reactive power generation and absorption, and load power factor adjustments, are examined using a novel electricity market equilibrium model that solves large-scale nonlinear power systems with asymmetric strategic firms. The algorithm implemented employs the linear supply function theory for bid-based pool markets. AC power flow analysis is used to represent the electricity network, incorporating variable price-responsive active and reactive load demands. The significance of the reactive power modeling in the electricity market equilibrium is demonstrated using the IEEE 14-bus and IEEE 118-bus systems. It is shown that variations on the reactive power in the system result in different market outcomes, as incentives are given to the strategic generating firms to alter their bidding strategies. The convergence characteristics of the IEEE 118-bus system are graphically presented and discussed to demonstrate the superior computational performance of the proposed algorithm in producing results under strict binding constraints and heavy transmission congestion conditions.

1. Introduction

Major reforms have taken place in the electricity sector around the world during the last two decades. The liberalization and deregulation of the power market has led to the replacement of its monopolistic structure by a more competitive environment. However, perfect competition was unlikely to be established due to the unique nature of the electricity market and the operational complexity of the generation, transmission and distribution of electrical energy. The result was the transformation of the electricity market into an oligopolistic structure with a small number of large participants, which have the ability of exercising market power to influence the overall market outcome for their benefit [1]. In order to provide insights regarding the oligopolistic electricity markets, power system designers were required to devise new market models based on the notion of economic equilibria [2] for the implementation of several market competition types. The technical aspects considered and the network representations employed vary between the models, depending on the scope of the particular research.

The model presented in this paper employs the linear supply function theory for the investigation of non-cooperative electricity market equilibria. The electricity network is represented using nonlinear AC power flow analysis in order to include the modeling of reactive power in the system and enhance the accuracy of the electricity market equilibrium solution. Such network modeling enables the examination of the electricity market equilibrium under different reactive power generation and absorption limits and different load power factors, showing the direct relation of the presence of reactive power in the system with the market equilibrium solution and the bidding strategies of the generating firms.

The structure of the rest of the paper is as follows. Section 2 provides an overview of the electricity market supply function equilibrium (SFE) models and the employment of different network representations, while it examines the reactive power interactions in the electricity market from the existing literature and outlines the key features of the proposed SFE model. The SFE market problem and the implementation of the solution procedure of this study are described in Section 3. Numerical results with discussions on the IEEE 14-bus and IEEE 118-bus systems for the investigation of the impact of the reactive power generation and absorption limits and of load power factor adjustments on the electricity market equilibrium are presented in Section 4. The performance of the proposed algorithm in solving large-scale nonlinear systems is examined in Section 5, where the convergence characteristics for

* Corresponding author. Tel.: +44 121 414 4298; fax: +44 121 414 4291.
E-mail addresses: a.petoussis@hotmail.com (A.G. Petoussis), x.p.zhang@ieee.org (X.-P. Zhang), SPetousis@eac.com.cy (S.G. Petoussis), k.r.godfrey@warwick.ac.uk (K.R. Godfrey).

0378-7796/$ – see front matter
doi:10.1016/j.epsr.2009.10.022