Electric Power Systems Research 81 (2011) 1161–1170

Contents lists available at ScienceDirect

Electric Power Systems Research

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

Congestion management impacts on bilateral electricity markets under strategic negotiation

Tao Huang[a,b,*], Ettore Bompard[b,c], Zheng Yan[a]

[a] Key Laboratory of Control of Power Transmission and Transformation, Ministry of Education (Dept. Electrical Engineering, Shanghai Jiao Tong University), Shanghai 200240, PR China
[b] Department Ingegneria Elettrica, Politecnico di Torino, Torino 10129, Italy
[c] Institute for Economic Research on Firms and Growth, CNR, National Research Council, Moncalieri (TO), 10024, Italy

ARTICLE INFO

Article history:
Received 6 October 2010
Received in revised form 2 December 2010
Accepted 14 January 2011
Available online 4 February 2011

Keywords:
Bilateral electricity market
Complex network
Bipartite network
Congestion management
Network formation
Strong stability

ABSTRACT

Congestion management design is key to a fair and efficient use of transmission facilities and an improvement of market efficiency. Emergence of bilateral electricity markets provides a more flexible, private and decentralized decision-making scenario, in which the self-interested players autonomously search for counterparts to negotiate profitable transactions. In competitive bilateral markets of imperfect and incomplete information and explicit consideration of the network constraints, which make the markets significantly complex, more sophisticated bargaining strategies and market evaluation tools are imperative to both players and regulators.

In this paper, under an assumption of imperfect and incomplete information, evolutionary bipartite complex network theory is employed to develop quantities bidding strategies through a dynamic game, in which the players drive the evolution of the network while maximizing their own utilities with explicitly considering the congestion management results. Resorting to adjustment bids, two congestion management schemes, with and without balancing bilateral transactions, are considered.

The approach is illustrated with an application to the IEEE30 test system, assessing the impact of different congestion management schemes on the negotiations, market equilibria, market performance and gaming opportunities for the market participants in congestion managements.

1. Introduction

Bilateral models and pool models are two reference paradigms with respect to the decentralized and centralized electricity markets, respectively [1]. In a bilateral market, producers and consumers meet one another in the market place to directly negotiate and sign a contract for the electricity on mutual consent of the price and MW amount, based on the independently distributed decision-making of each participant driven by the profit maximization [2]. In a pool market, on the contrary, consumers and producers bid into a centralized organization who determines the market prices and schedules for each participant [3]. Either of the paradigms would be adopted to develop an electricity market. However, neither can be found solo extant in real markets, many witnesses of coexistence can be found in many parts of the world, such as PJM [4], ISO-NE [5], MISO [6] in the US, and ENTSO-E [7] in Europe.

Compared with the pool model, a bilateral market is more flexible and less transparent due to the private and direct negotiations and multilateral trades among producers and consumers. Unlike in the pool model, a player can decide her counterparts and the contracted amount and price with each of them, which requires more sophisticated approaches for strategic negotiation. Several papers concerning the bilateral model have been published in recent years. Based on a generic generating cost matrix and the loads' willingness to pay vector, [8] derived the necessary and sufficient conditions for Nash equilibrium bidding strategy under complete information. On an assumption that each producer naively assumes its output will not affect transmission prices, Cournot models of imperfect competition among electricity producers were formulated in [9] as mixed linear complementarily problems, incorporating arbitrage behaviors and congestion prices scheme for transmission. Based on estimates of the opponent's costs and strategy, a single stage bargaining model between two players was developed for a non-cooperative case [10]. In [11], a bilateral market model was proposed to anticipate possible bilateral transactions, described as a financial network constrained by a physical network, based on a pair-wise stable network.

Both bilateral and pool models need to satisfy system feasibility usually represented by a set of physical and operational constraints. Security and feasibility of a system are charged by an independent system operator (ISO) [12]. If bilateral contracts incur infeasibility,

* Corresponding author at: Dept. Electrical Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China. Tel.: +86 21 34205431; fax: +86 21 34205417.
E-mail addresses: tao.huang@polito.it, tao.huang.new@gmail.com (T. Huang).

0378-7796/$ – see front matter
doi:10.1016/j.epsr.2011.01.006

congestion management (CM) will be undertaken to remove all of the violations. The generation patterns, market efficiency, network congestion and security margins resulting from a bilateral market could be different from those in a pool market [13].

CM methods may consider different time frames, such as optimal allocation of available capacity among participants before the operating time or effective alleviation of congestion during the operation. They may be divided into different categories like non-/market based or implicit/explicit auction. In the Nordic electricity market, market splitting is employed in the day-ahead market, while congestions are relieved by counter-trades [14]. In the tri-lateral coupling of the Belgian, Dutch and French electricity markets, market coupling is used to deal with the interconnection congestion [15]. In ETRANS (Switzerland), a zero-sum redistribution of the generation schedules based on bids from generation companies is resorted to alleviate congestion at a minimal cost [16]. In the US, location marginal price (LMP), which reflects transmission limitations and corresponding congestion costs over the system, is adopted in the standard market design and widely implemented over regional markets such as PJM, ISO-NE, MISO. In [17], a method for determining both firm and non-firm flows, resulting from a market-based operating entity dispatching on external parties' flowgates, was proposed to affect the coordination of CM activities between PJM and MISO. Besides the congestion management methods based on the traditional market mechanism, other alternatives were also adopted to address this problem. [18] proposed an OPF-based security-constrained redispatching model including FACTS devices to resolve system congestion and security issues, using full AC equations and explicitly considering security limits through a stressed loading condition. Security issues sometimes are considered in the congestion management as well [18,19], for example, replacing the commonly used offline transmission capacity limits related to stability by optimal power flow-related constraints ensuring some level of voltage security, [19] devised a congestion relieving algorithm resulting in better economic outcomes for players.

The specific feature of a bilateral market makes it difficult to extrapolate by usual approaches, such as standard microeconomics and game theory. It prompts a need for the development of new approaches and tools.

In this paper, we propose an *evolutionary bipartite complex network* based model for the assessment of impacts of different CM schemes on negotiations, market performance and the provision of gaming opportunities for participants. The market is modeled using a *bipartite complex network,* in which the nodes represent the producers and consumers and the weighted links among them represent the transactions and their amounts. The formation of a network describing the bargain process is obtained by a set of coalitional derivations. The bilateral bargain process is modeled via a *dynamic game* driven by the maximization of the utility for an individual participant, explicitly considering CM results. The concept of *strong stability* is used to detect the market equilibrium obtained from the evolution of networks. Unlike the traditional simulation methods such as conventional economic theories which simplify the question based on reductionism to seek analytical solutions to figure out the consistent behaviors of the players with the overall pattern, the evolutionary bipartite complex network approach focuses on the emergence of the transaction patterns and the corresponding impacts of relevant issues. Compared with the agent based simulation, our approach inherently embedded the concept of network stability coherent with the equilibrium commonly used in the economics and the dynamic formation of a series of networks usually converged to a stable state.

The decision-making process, considering network constrains and CM, may lead to multiple equilibria. The market equilibria are statistically analyzed with the help of a set of indices.

Table 1
Framework of the approach.

	Market context	Algorithm
Environment	m sellers and n buyers meet in the market	Random selection of a node or a pair
Decision-making	Buyers and sellers decide whether to negotiate a new intent for transactions or modify the existing ones	Optimization problem
Market equilibrium	Meetings in the market continue till an equilibrium	Strong stable network

The rest of the paper is organized as follows. In Section 2, the framework of the proposed approach and relevant assumptions are introduced. In Section 3 the bilateral market environment is described as a complex network. In Section 4, CM schemes in bilateral markets are introduced and two schemes are formulated. In Section 5, strategic negotiation of market participants are mathematically described based on the concept of valid coalitions. Numerical studies and conclusions are given in Sections 6 and 7, respectively.

2. Framework of the approach and assumptions

The proposed approach aims to evaluate the impacts of different CM schemes on market results under strategic negotiations. The core of the assessment is to find meaningful market equilibria. To achieve this, we describe a bilateral market in three phases: *environment*, *decision-making* and *equilibrium check* (Table 1). The environment consists of all the market data and simulation parameters; the decision-making, considering the congestion management based on the DC power flow model, drives the evolution of the network; and the equilibrium check distinguishes and records all stable networks.

The following sections dedicate to model each phase according to Table 1. Precisely, Sections 3.1 and 3.2 describe the market environment; Section 3.3 rigorously expresses the criterion for equilibrium; Sections 4 and 5 focus on how to make strategic negotiation by calculating relevant revenues and costs.

For modeling purposes, we state here the assumptions we impose on all the relevant aspects:

- We assume players can freely discuss their strategies, but not make binding commitments; therefore, they can withdraw any intent for transactions till the agreements are finalized.
- The transmission network parameters used for bilateral transactions feasibility check and congestion management can be either the ATC, NTC [20] or those for the long term FTR auctions, both of which can cover the whole duration of the bilateral transactions.
- Normally, a bilateral contract embraces mid-term or long-term period. However, based on the network parameters assumption above and due to the homogeneity of a contact during its whole duration with respect to power delivered during the specific hours, without loss of generality, we use hourly based units for articulateness.
- We assume the negotiation cost is negligible and any other costs related to a transaction are equally shared by the involved pair.
- We assume each generator belongs to one producer and each load belongs to one customer for the simplicity, but the approach applies also to an extensive model with multiple generators belonging to a generation group or multiple loads belonging to a load serving entity.
- Although all strategic behaviors in every stage can be incorporated into the proposed approach, for the sake of simplicity and articulateness, we assume the strategic bidding only applies in the negotiation, while strategic bidding and collusive arbitrage in the CM are prohibited.