



Review of real-time electricity markets for integrating Distributed Energy Resources and Demand Response



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HIGHLIGHTS

- This paper reviews typical RTMs in the North America, Australia and Europe.
- The successful RTM experiences are summarized and discussed in three groups.
- Technical overview of the RTMs integrating DER and DR is presented.

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ABSTRACT

The high penetration of both Distributed Energy Resources (DER) and Demand Response (DR) in modern power systems requires a sequence of advanced strategies and technologies for maintaining system reliability and flexibility. Real-time electricity markets (RTM) are the non-discriminatory transaction platforms for providing necessary balancing services, where the market clearing (nodal or zonal prices depending on markets) is very close to real time operations of power systems. One of the primary functions of RTMs in modern power systems is establishing an efficient and effective mechanism for small DER and DR to participate in balancing market transactions, while handling their meteorological or intermittent characteristics, facilitating asset utilization, and stimulating their active responses. Consequently, RTMs are dedicated to maintaining the flexibility and reliability of power systems. This paper reviews advanced typical RTMs respectively in the North America, Australia and Europe, focusing on their market architectures and incentive policies for integrating DER and DR in electricity markets. In this paper, RTMs are classified into three groups: Group I applies nodal prices implemented by optimal power flow, which clears energy prices every 5 min. Group II applies zonal prices, with the time resolution of 5-min. Group III is a general balancing market, which clears zonal prices intra-hourly. The various successful advanced RTM experiences have been summarized and discussed, which provides a technical overview of the present RTMs integrating DER and DR.

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1. Introduction

In the last decades, the restructuring and deregulation of power system change the basic structure of system operation and planning. In the new deregulated environment, electricity and corresponding prices are determined and traded in the markets, respectively. There are different categories of electricity market architectures and pricing schemes prevalent in the power systems around the world according to their local economical characteristics and infrastructure conditions.

The current development tendency is that, industrialized countries increasingly penetrate their power systems by renewable energies, such as wind energy and photovoltaic for the purposes of low-carbon emissions and environmental protections, while expecting to increase the asset utilization of high electrification of transportations and efficient heating facilities, e.g., Electric Vehicles, Heat Pumps, Combined Heat and Power System (CHP) [1]. These factors will have high impacts on power systems' operation and planning, especially influencing the distribution grids where connecting most of the small Distributed Energy Resources (DER) and end-consumers possibly acting as Demand Response (DR) [2]. The recent rapid development of communication technologies on telemetry and remote control, e.g., smart meters, has established the foundation of Real-time electricity markets' (RTM) implementation [3].

One of the main functions of RTMs in modern power systems is to build an efficient and effective transaction platform for small DER and DR to actively provide balancing services during power system operations [4]. Small-size DERs and DR integrated via aggregators have the potentials to provide faster (e.g. 5 min) balancing services than the large conventional generating units, which usually provide balancing services within 15–20 min.

Simultaneously, the RTM can also coordinate with the conventional Manual Reserve Market, which provides sufficient reserve capacity for supporting the real time balancing e.g., tertiary reserve according to the UCTE's (Union for the Coordination of the Transmission of Electricity) definition [5]. DER can help lessen peak-load, reduce reliance on large central fossil fuel generation, improve asset utilization, and accelerate interoperability. DR enables advanced demand management, encourage customers' active participations, and boosts digital communication technologies [6,7]. The prosumers, who possibly perform as both DER and DR alternatively, respond to real-time electricity prices by means of Information and communication technology systems (ICT), will bring the flexibility of power system operations and change the structure of electricity markets [8].

This paper reviews advanced typical RTMs coordinated with the relevant ancillary service markets, which maintain reliable and secure operation of power systems, respectively in the North America, Australia and Europe. In this paper, RTMs are generally classified into three groups:

- (1) RTM Group I: the RTMs apply nodal prices by Optimal Power Flow (OPF) implementation, which clear energy prices every 5 min, represented by PJM.
- (2) RTM Group II: the RTMs apply zonal prices, with the time resolution of 5 min, represented by AEMO.
- (3) RTM Group III: the general Balancing Markets (BM), which clear zonal prices intro-hourly, e.g., 45 min, which are applied by most European markets.

The RTM architectures and corresponding incentive policies for integrating DER and DR in electricity markets are described and discussed in the paper.

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