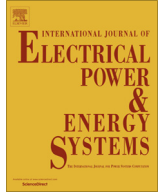




Contents lists available at ScienceDirect

## Electrical Power and Energy Systems

journal homepage: [www.elsevier.com/locate/ijepes](http://www.elsevier.com/locate/ijepes)

## Design of performance-based frequency regulation market and its implementations in real-time operation

Zhongwei Wang<sup>a,\*</sup>, Jin Zhong<sup>a,b</sup>, Jianhui Li<sup>c</sup><sup>a</sup> Department of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong Special Administrative Region<sup>b</sup> Luleå University of Technology, Sweden<sup>c</sup> Guangdong Power Dispatch Centre, Guangzhou, China

## ARTICLE INFO

## Article history:

Received 6 April 2016

Received in revised form 17 July 2016

Accepted 27 October 2016

Available online xxxx

## Keywords:

Ancillary service

Frequency regulation market

Regulation capacity

Regulation mileage

Regulation market design

## ABSTRACT

The importance of the performance of frequency regulation has already been acknowledged by regulators and Independent System Operators (ISOs). A performance-based frequency regulation market model considering both regulation capacity and regulation mileage constraints is proposed in this paper. In the proposed market, high-performance regulation resources have higher priorities to be selected in the market. Market clearing prices are derived with Lagrange relaxation. The analysis of the components of market clearing prices accurately indicates the correlation between regulation capacity and regulation mileage. To accommodate the proposed regulation market design, AGC allocation algorithm is adjusted based on the market clearing results. The clearing procedure of the market model is demonstrated on an illustrative case. The proposed market design is tested and verified with market simulations and system dynamic simulations. Simulation results are discussed and compared to show the effectiveness of the proposed market design.

© 2016 Elsevier Ltd. All rights reserved.

## 1. Introduction

Frequency regulation service plays an important role in power system operation for its real-time balancing of electricity supply and demand. In a deregulated system, frequency regulations are procured through ancillary service markets [1]. In the United States, the independent system operator (ISO) clears energy market and ancillary service market simultaneously, determining the energy schedule and regulation capacity for each resource, as well as the energy clearing price and regulation market clearing price [2–4]. In the Nordic system, a major part of frequency regulation service is settled by long-term bilateral contracts and the rest portion is procured in a merit-order based balancing market [5]. During the past few decades, the increasing penetration of intermittent renewable energy generations, including wind and solar energy, introduces more uncertainties to power system operation, increasing the need for fast ramping regulation resources [6,7] to provide frequency control. Emerging energy storage technologies, such as battery and flywheel energy storage, are ideal regulation resources due to their fast responding capability and accurate controllability [8,9]. Therefore, it is necessary for the sys-

tem operator to provide incentives to encourage these fast resources to participate in the regulation market.

Federal Energy Regulatory Commission (FERC) indicated in the Order 755 [10] that in order to encourage fast-ramping resources to provide regulation services, market design modifications should be implemented. Payments to the resources on regulation should include two components: a capacity payment representing the lost marginal cost of a resource, and a performance payment reflecting the actual regulation performance of the resource. To fulfil FERC Order 755, ISOs have made their market modifications. The concept of “Mileage”, indicating the sum of absolute changes in generation outputs between different control intervals in a given period, has been widely accepted by ISOs to evaluate the performance of regulation resources [11].

In PJM Interconnection (PJM), the modified regulation market is implemented in the day-ahead market and is subject to real-time adjustment [12]. Resources willing to provide regulation services submit a regulation capacity offer price and a regulation mileage offer price. The market operator adjusts the offer of each resource based on its historical regulation performance. Then, the regulation offer price of the resource is calculated by summing up its adjusted regulation capacity offer price and its adjusted mileage offer price. In PJM, the operator clears the market by co-optimizing energy and regulation for each operating hour of the day subject to regulation capacity constraints. To emphasize regulation performance, the

\* Corresponding author.

E-mail address: [zwwang@eee.hku.hk](mailto:zwwang@eee.hku.hk) (Z. Wang).

highest adjusted mileage offer price among all selected resources determines the market mileage clearing price. The market capacity clearing price is calculated by the regulation offer price of the last selected resource minus the market mileage clearing price. After real-time operation, the market is settled based on the pre-determined capacity assigned to each resource, market clearing prices, and actual mileage obtained from each resource. Midcontinent ISO (MISO) implements a frequency regulation market similar to PJM except adjusting submitted offers for each resource individually [13,14]. MISO simplifies the process by using a system mileage multiplier, which is obtained based on the average historical performance of all resources. The regulation offer price of each resource is calculated by its capacity offer price plus the product of its mileage offer price and the system mileage multiplier. California ISO (CAISO) clears the regulation market subject to both regulation capacity constraints and regulation mileage constraints [15], which is different from PJM and MISO that are only with regulation capacity constraints. In this way, the mileage selected from a specific resource is affected by the selected capacity of the resource as well as its historical mileage. While CAISO has proposed to include both capacity and mileage constraints, a detailed formulation of the pricing mechanism has not been provided.

In real-time operation, regulation resources adjust their generation outputs in response to the system Automatic Generation Control (AGC) signals. With the implementation of a performance-based regulation payment, some system operators have modified or are modifying their AGC systems. For example, PJM has divided the regulation signals into traditional regulation signals (RegA), which are sent to conventional units, and fast response regulation signals (RegD), which are sent to fast-ramping resources [16]. In MISO, it is under discussion whether to set a separate regulation group for fast-ramping resources that are always deployed first or to modify the AGC distribution logic for these high-performance resources [17].

The performance-based frequency regulation payment has proven its effectiveness in U.S. power systems for its improving the system frequency quality and reducing the system regulation requirement [18]. In Europe, currently, there is no regulatory policy to include a regulation performance payment. Major European balancing markets compensate resources providing regulation with a payment for reserved capacity and a payment for real-time deployed energy [19]. However, the importance of fast-ramping storage units to provide regulation has already been acknowledged. For instance, in Germany, some pilot battery projects have been launched to manage frequency regulation and integrate renewable energy sources [20].

In addition to the practices of different system operators, some progress in recent academic papers also broadened the studies in this area. In [21], the planning issue of storage devices in a performance-based regulation market environment is addressed. In [22–24], optimal operation strategies are proposed for large-scale storage units and electric vehicles to maximize their profits in a performance-based regulation market. In these papers, regulation market clearing prices and AGC signals are assumed to be fixed. In [25–27], modified regulation market models are proposed to deal with the fluctuations caused by renewable energy sources by considering the system dynamics; however, the payment for regulation performance is not taken into account.

In this paper, to accurately present the relationship between regulation capacity and regulation mileage in the market clearing process, a performance-based regulation market model is first developed and their relationships are analysed based on the market simulation results. Furthermore, market-clearing prices for regulation capacity and regulation mileage are obtained and analysed. To reflect the clearing results from the proposed market model in real-time operation and to deploy regulation resources appropriately, an AGC allocation method is proposed. The proposed AGC allocation method uses a pro-rata approach and determines the

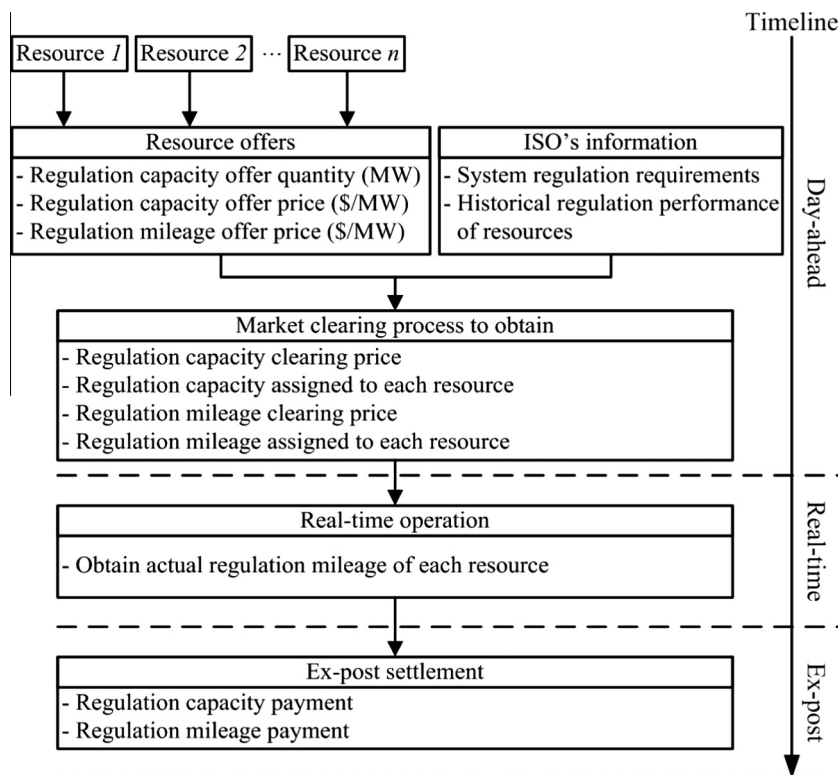


Fig. 1. Scheme of proposed performance-based frequency regulation market.

Download English Version:

<https://daneshyari.com/en/article/4945659>

Download Persian Version:

<https://daneshyari.com/article/4945659>

[Daneshyari.com](https://daneshyari.com)