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Mixed integer non-linear programming and Artificial Neural Network based approach to ancillary services dispatch in competitive electricity markets

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HIGHLIGHTS

- Ancillary services market management.
- Ancillary services requirements forecast based on Artificial Neural Network.
- Ancillary services clearing mechanisms without complex bids and with complex bids.

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ABSTRACT

Ancillary services represent a good business opportunity that must be considered by market players. This paper presents a new methodology for ancillary services market dispatch. The method considers the bids submitted to the market and includes a market clearing mechanism based on deterministic optimization.

An Artificial Neural Network is used for day-ahead prediction of Regulation Down, regulation-up, Spin Reserve and Non-Spin Reserve requirements.

Two test cases based on California Independent System Operator data concerning dispatch of Regulation Down, Regulation Up, Spin Reserve and Non-Spin Reserve services are included in this paper to illustrate the application of the proposed method: (1) dispatch considering simple bids; (2) dispatch considering complex bids.

1. Introduction

Electric power industry is moving towards an increasing competition, with a variety of services previously provided by electric utilities being progressively unbundled [1–7]. Initially the attentions have mainly focused on the energy market but ancillary services (AS) are gaining more and more importance. Ancillary services have an essential role in the operation of electricity markets [8–12]. AS are generally defined as those services that are important to achieve targeted goals on power system security, reliable operation, frequency stability, as well as on voltage level and stability [13–15], in order to cover generation and transmission contingencies.

The definition of ancillary services prices and how those prices should change regarding the operating decisions is becoming a major issue due to the changes in the market structure [9,16]. The creation of a market for ancillary services aims at achieving mutual benefits for buyers and sellers. The Independent System Operator (ISO) aims at obtaining the necessary resources in order to maintain the system security at minimum cost, while providers look for the maximization of their profits from the sale of ancillary services.

Ancillary services are necessary, according to the Federal Energy Regulatory Commission (FERC), to support the power transmission from sellers to buyers, whereas the control areas and transmission

Abbreviations: AS, ancillary services; ISO, Independent System Operator; FERC, Federal Energy Regulatory Commission; RU, Regulation Up; RD, Regulation Down; AGC, Automatic Generation Control; SR, Spin Reserve; NSR, Non-Spin Reserve; MASCEM, multi-agent simulator of competitive electricity markets; SCUC, Security Constrained Unit Commitment; SCED, Security Constrained Economic Dispatch; CAISO, California Independent System Operator; ANN, Artificial Neural Networks; CM, clearing mechanisms; FD, values of the Forecasted Demand; RS, Required Service; GAMS, General Algebraic Modeling System; MAPE, Mean Absolute Percentage Error; LP, linear programming; MINLP, mixed integer non-linear programming.

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Nomenclature

N	total number of bids
i	bid index (i = 1, 2, ..., N)
k	ancillary service index (1 for Regulation Down, 2 for Regulation Up, 3 for spin, and 4 for non-spin)
T	total number periods in hours
t	period index (t = 1, 2, ..., T)
$Q_{k,t}$	total capacity requirement for ancillary service k in period t
$Cmax_{i,t}$	maximum capacity of bid i in period t
$C_{k,i,t}$	capacity of bid i for ancillary service k in period t
$X_{k,i,t}$	accepted capacity of bid i for ancillary service k in period t
$PR_{k,i,t}$	capacity reserve price of bid i for ancillary service k in period t
$PE_{k,i,t}$	energy reserve price of bid i for ancillary service k in period t
p	estimated probability of using reserve energy acquired for AS
Mm_i	minimum limit of remuneration for the whole 24 h
$Y_{k,i,t}$	decision variable of bid i for service k in period t
$Ylo_{k,i,t}$	minimum working hours of bid i for service k in each time period
$Yup_{k,i,t}$	maximum working hours of bid i for service k in each time period
Mh_i	minimum consecutive working hours of bid i

utilities have the obligation to maintain a reliable operation of interconnected transmission system [17].

Regulation services – Regulation Up (RU) and Regulation Down (RD) – are the first level acting reserves which are updated around every 4 s depending on the system operator. The regulation keeps the continuous matching between load and generation and is controlled by Automatic Generation Control (AGC) systems [18,19].

The Spin Reserve (SR) is one of the most important AS required for maintaining power system reliability following a major contingency. In the same way, Non-Spin Reserve (NSR) has an important role in keeping the system security, since this reserve is used when SR cannot satisfy the reserve needs. Short-term prediction of day-ahead reserve requirement helps the ISO making effective and timely decisions. Moreover, based on these forecasts, market participants can make decisions concerning their bidding strategies for day-ahead SR market [18,19].

Two alternative methods are available for energy and ancillary service provision: simultaneous procurement and separate procurement [20], with advantages and drawbacks of each of these solutions. Because most ancillary services are provided by the same equipments that produce energy, the energy and AS markets are linked so any problem in one of these markets may cause a problem in the other [21].

In recent years, ancillary service markets design has become an important work area. Designing options of bid selection protocols and settlement rules for ancillary service markets are presented in [22]. An ancillary framework for managing power system security, based on a market for ancillary services, is presented in [23]. A detailed formulation of simultaneous energy and ancillary service auctions for integrated market systems by an optimal power flow is presented in [24]. A Security Constrained Unit Commitment model for energy and ancillary services auction, which can be used by an ISO to optimize reserve requirements in electricity markets, can be found in [25]. In [13], Vale et al. present an approach using linear programming and genetic algorithm approaches that has been used in MASCEM, a multi-agent electricity market simulator, to deal with ancillary services market simulation. An Artificial Neural Network approach for day-ahead RD, RU and NS forecasting which has been included in MASCEM [26] is described in [19]. [27] presents two mathematical models, the Security Constrained Unit Commitment (SCUC) and the Security Constrained Economic Dispatch (SCED) that are used to perform Unit Commitment and Economic Dispatch respectively in CAISO (California ISO) day-ahead and Real Time Markets.

It is well known that the economic selling bids of energy that sellers present to the market operator can be simple or integrate complex conditions. The simple bids are economic offers of energy sale that sellers present for each time period and for each generation unit of which they own with a price and a quantity of energy. In most of the cases the bids are not simple and integrate complex conditions of sale in order to achieve the producers (sellers) objectives and the needs of the ISO. The complex bids are those that comply with the requirements for the simple bids and also integrate any of the allowed conditions, such as: minimum remuneration for each bid, minimum working hours, and minimum consecutive working hours. Thus, in order to accommodate the objectives of the producers (sellers) and the needs of the ISO this paper proposes a methodology for AS market management and simulation. This methodology includes two distinct phases: the AS requirements forecasting and the AS dispatch. The AS requirements forecast based on Artificial Neural Networks (ANN) has been previously proposed by some of the authors of this paper [19]. The ANN is trained using AS historic data and are able to determine the amount of power to be guaranteed for each AS. The AS dispatch considers the bids submitted to the market and includes a market clearing mechanism based on linear programming and other considering complex bids based on mixed integer non-linear programming.

After this introduction section, this paper is organized as follows: Section 2 deals with ancillary services in electricity markets. Section 3 presents the methodology for the problem under study. Section 4 presents two case studies and the discussion of the obtained results. The presented case studies use real AS data from California Independent System Operator (CAISO) to forecast AS requirements. Finally, Section 5 presents the most relevant conclusions of the presented work.

2. Ancillary services

Generation must handle the load requirements; however, satisfying the demand is not the only requirement for power system operation. To ensure power system security and reliability, it is necessary to guarantee some extra energy generation, which can be seen as a set of additional services known as ancillary services (AS).

Generally, the Independent System Operator (ISO) has the responsibility of determining, getting and using the required AS.

In order to maintain the system in a secure operation state, the ISO must be able to [28]:

- control the frequency by keeping the load-demand balance;
- control the system voltage profile within certain bounds;
- maintain the system stability;
- prevent overloads in the transmission system;
- restore portions or entire system when and if required.

Besides this list, the system operator must also maintain the system integrity in the presence of unexpected events and contingencies.