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Benefits of solar forecasting for energy imbalance markets

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A B S T R A C T

Short term electricity trading to balance generation and demand provides an economic opportunity to integrate larger shares of variable renewable energy sources in the power grid. Recently, many regulatory market environments are reorganized to allow short term electricity trading. This study seeks to quantify the benefits of solar forecasting for energy imbalance markets (EIM). State-of-the-art solar forecasts, covering forecast horizons ranging from 24 h to 5 min are proposed and compared against the currently used benchmark models, persistence (P) and smart persistence (SP). The implemented reforecast of numerical weather prediction time series achieves a skill of 14.5% over the smart persistence model. Using the proposed forecasts for a forecast horizon of up to 75 min for a single 1 MW power plant reduces required flexibility reserves by 21% and 16.14%, depending on the allowed trading intervals (5 and 15 min). The probability of an imbalance, caused through wrong market bids from PV solar plants, can be reduced by 19.65% and 15.12% (for 5 and 15 min trading intervals). All EIM stakeholders benefit from accurate forecasting. Previous estimates on the benefits of EIMs, based on persistence model are conservative. It is shown that the design variables regulating the market time lines, the bidding and the binding schedules, drive the benefits of forecasting.

1. Introduction

The electricity system is undergoing an inevitable change to address increased variability in generation and net load, introduced by intermittent generators, mainly wind and solar. Many approaches to mitigate the adverse effects of ramping have been proposed, e.g. increased storage capabilities, resource and net load forecasting, demand response, etc. The core of all solutions for integrating higher levels of variable wind and solar generation is to increase the flexibility options available in the grid [1,2]. Recently, regulating authorities in several jurisdictions reorganized the market environments to allow flexible energy trading schedules, designed to better exploit spatial and temporal diversity in generation and demand. Historically, this reorganization started in Northern Europe by allowing short-term, cross-border electricity trading, driven by the need to integrate increasing shares of variable wind generation.

In October 2014, the Energy Imbalance Market (EIM) in the Western Interconnection was opened in United States of America interconnecting over 30 participating balancing authorities (BAs) in USA and Canada. This allows for generation and demand balancing across Balancing Authority Areas (BAA) on 15 min and 5 min timescales with California Independent System Operator (CAISO) oversight. Previous to the opening, all the Balancing Authorities (BA) were responsible to balance generation and demand for their own area. Now, the ISO can dispatch and share resources across the participating BAAs to balance energy of all BAs. All EIM market participants are mandated to provide a continuous feed of specified forecasts to the ISO. Energy imbalances caused by errors in the forecasts and bidding are settled by the defined settling regulation e.g. according to the United States Federal Energy Regulatory Commission (FERC) Order 890, for intermittent renewable generators, imbalances greater than 7.5% or 10 MW are settled at 125% incremental cost or 75% decremental cost of providing the imbalance energy. In contrast to the dominance of wind as intermittent generator in Northern Europe, solar is the dominating intermittent energy source in many regions in the Western Interconnection with tremendous expected growth rates (e.g. California).

On this background, this study aims to analyze and quantify the benefits of solar forecasting for EIM operations. To achieve this, solar forecasts are implemented to cover all necessary forecast horizons for EIM operations. All implemented forecasts are state-

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of-the-art methodologies based on broadly available methods, relying on low-cost instrumentation and publicly available data. The contributions of this study are: 1) reforecast methodology to forecast day-ahead global irradiance 2) features based optimized short-term solar forecasting 3) analysis of solar forecast errors for the forecast horizons related to electricity markets, especially the short-term EIM market in the Western Interconnection and 4) detailed analysis on the role of solar forecasting in EIM in terms of uncertainty and estimation of flexibility reserves from the perspective of market operator and participants.

More detailed discussion on the EIM and previous work on solar resource forecasting are provided in Section 2, the data sets used are described in Section 3, methods for solar forecasting are explained in Section 4, results are discussed in Section 5, the value of forecasting for EIM is shown in Section 6 and conclusions are drawn in Section 7.

2. Energy imbalance markets

2.1. Goals

The main objective for the introduction of EIMs is to reduce imbalances between demand and generation without ancillary services or additional reserves by enabling regulated, short-term energy trading between interconnected balancing areas. Without EIMs, resources were not shared between the balancing areas. The individual balancing area authorities had to schedule and keep operating reserves to handle imbalances. For the EIM in the Western Interconnection, after scheduling for 15 min market, the 5 min market is executed to automatically procure resources to balance expected imbalances between generation and demand in 5 min time intervals. Taking the advantage of increased geographical diversity in generation and load profiles, the main benefits of this market are reduced operating reserves capacity, enhanced reliability, reduced costs and automatic dispatch, and real-time visibility.

2.2. Previous work

This section covers a short summary of previous work, relevant for EIMs. A review on real-time markets is presented in Ref. [3]. An overview of previous EIM studies can be found in Ref. [4]. They include a comparison of market regulations based on assumptions, annual benefits, and geographic scope. The study includes benefits of the implemented EIM between ISO and PacifiCorp. The impact for EIM, for grids with high levels of wind penetration, was studied in Ref. [5]. They show that the introduction of EIMs enables reserve requirement reductions which is beneficial for all EIM participants. Furthermore, they show that the failure or refusal of participation by as little as one entity can reduce the benefits for all other participants in the market. Using forecasts as a decision variable the bidders and market operator can commit or de-commit in case of high or low energy production [6]. An evaluation of energy balance and imbalance settlements in Europe is presented in Ref. [7].

A general framework for analyzing various components of market participation for wind generators was proposed in Ref. [8]. They discuss the value of information contained in forecasts for grids with high wind penetration. Conclusions cover that forecasting has a high economic value for variable wind energy sources. For current status of wind penetration in CAISO, investment in short-term wind forecasting is precarious, whereas in future scenarios with high wind penetration levels, forecasting can evolve into an important decision variable for real-time market operation, e.g. economic dispatch in the CAISO area [9]. A detailed analysis on organized markets in the Western Interconnection can be found in Ref. [10]. It highlights the factors influencing the success of EIMs, such as cost allocation, transmission rights, participation of various BAAs, stakeholders and discusses the alternatives to organized markets, for instance Intra-hour Transaction Accelerator Platform, the Dynamic Scheduling System, Balancing Authority Reliability-based Control, Area Control Error Diversity Interchange, Enhance Curtailment Calculator, etc. While these alternative market setups might be beneficial in certain cases, the regulating authorities decided to operate an EIM in the Western Interconnection. The focus of our work is the EIM in the Western Interconnection in the United States.

Most of the studies on the impact of EIM on Western and Eastern Interconnection assume forecasts to be persistent [6]. However, there has been tremendous progress in the field of solar energy resource forecasting over the past decade. Hence, previous studies provide a conservative estimate of reserves. In this study, we seek to quantify the benefits of state-of-art-solar solar forecasts for the EIM. The next section covers key design variables of EIMs and current solar forecasting methods that can be utilized for EIM participation and operation.

2.3. Market design variables

The two fundamental concepts for energy imbalance markets are balance responsibility and imbalance settlements [7]. Balancing responsibility covers the processes from market opening, to binding and market execution. The key variables for balance responsibilities are: (1) program time unit (PTU), defined as the time window for which bids are submitted and base schedules are awarded. (2) Scope of balancing, defined as the magnitude of necessary generation change. (3) Gate closure time ($GCT_{p/o}$); defining the time when the option to submit or modify a bid expires. The GCT_p is for market participants while the GCT_o is time when schedules are binded from the operator. (4) Types of imbalances, depending on if over- or under-generation occurs. (5) Closed (zero imbalance) or open (occurring imbalance) portfolio positions and (6) look ahead time (LAD), defining the ahead time horizon considered for running the optimization to schedule awards.

The design of imbalance settlements define the detailed setup of penalties associated with wrong forecasts and market bids. Details about imbalance settlements can be found in Ref. [7]. In general, it covers the frequency of settlements, regulations and pricing of imbalances for each market participant.

The discussed variables allow for broadly varying market designs. The specific regulation of EIMs vary greatly for different world regions. For instance, in Norway, the first GCT of market execution is 7 pm local time on the day before the market is executed. In Sweden, it is 4 pm and in Finland it is 4:30 pm. The PTU in these regions ranges between 60 and 15 min. In the Western Interconnection the first GTC before market execution is 40 min and PTUs are 15 to 5 min. More details for European EIMs can be found in Ref. [7] and for the Western Interconnection, the in-depth details are provided below.

The PTU and GCT are the key technical drivers of imbalance markets.

2.4. EIM in Western Interconnection

The Western Interconnection Energy Imbalance Market (WI EIM) is a centralized and coordinated real-time energy market, operating at 15 and 5 min time intervals. Before the introduction of the WI EIM, resources were not shared between the participating BAAs. Each BA had to independently schedule operating reserves and backup resources. With the introduction of the WI EIM with over 30 participating BAAs, generation and demand can be