Energy Policy 67 (2014) 531–542

Contents lists available at ScienceDirect

Energy Policy

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

Electricity market models and RES integration: The Greek case

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HIGHLIGHTS

- Analysis of the Greek electricity market for the next 7-year period (2014–2020) based on hour-by-hour simulation.
- Five different RES technologies are considered with emphasis on PV integration.
- A power pool (for 2014) and a power exchange (for 2015–2020) are considered.
- Various market indicators are used for the analysis of the impact of the RES integration on the Greek electricity market.
- Two alternative tariff schemes for the compensation of the new ground-mounted PV units from 2015 onwards are investigated.

ARTICLE INFO

Article history:
Received 20 September 2013
Received in revised form
18 November 2013
Accepted 25 November 2013
Available online 18 December 2013

Keywords:
Day-ahead market
RES integration
Wholesale electricity market

ABSTRACT

This paper presents an extensive analysis of the Greek electricity market for the next 7-year period (2014–2020) based on an hour-by-hour simulation considering five different RES technologies, namely wind, PV, small hydro, biomass and CHP with emphasis on PV integration. The impact of RES penetration on the electricity market operation is evaluated under two different models regarding the organization of the Greek wholesale day-ahead electricity market: a mandatory power pool for year 2014 (current market design) and a power exchange for the period 2015–2020 (Target Model). An integrated software tool is used for the simulation of the current and the future day-ahead market clearing algorithm of the Greek wholesale electricity market. Simulation results indicate the impact of the anticipated large-scale RES integration, in conjunction with each market model, on specific indicators of the Greek electricity market in the long-term.

1. Introduction

In the past 25 years, wholesale electricity markets have emerged in several countries to facilitate the competitive operation of the electricity sector (Stoft, 2002). In this context, large volumes of electric energy are usually traded in centrally organized day-ahead markets, which may take the form of either power exchanges or power pools (Stoft, 2002; Kardakos et al., 2013).

In parallel with the electricity market restructuring, the increasing environmental concerns for global warming have promoted the use of Renewable Energy Sources (RES) worldwide. The European Union (EU) has established the common target "20–20–20" (European Commission, 2009a) among all Member States aiming to combat climate change and increase the EU's energy security while strengthening its competitiveness. The share of RES in the electricity production is expected to increase to 30–35% by 2020 (European Renewable Energy Council, 2004). This goal motivated the EU countries to provide incentives for the increase of RES installed capacity (especially wind and PV) across Europe.

Besides the obvious environmental benefits, the increasing share of intermittent RES electricity production poses new challenges to the efficient management of the power systems and the operation of the electricity markets, since it can seriously affect the short-term scheduling of the conventional generating units, the maintenance scheduling of generating plants and transmission lines, the required levels of system reserves, the wholesale electricity prices, etc.

In this context, the research community has focused lately on the development of new methods and tools to tackle these problems and provide effective solutions towards the large-scale RES integration. An approximation algorithm for the unit commitment problem incorporating wind generation forecasts in the dispatch decisions for the investigation of the wind power effect on CO_2, SO_2 and NO_x emissions is presented in Denny and O' Malley (2006). Li and Kuri (2005) presented a dynamic programming approach for the solution of the weekly unit commitment problem at hourly resolution, in order to evaluate the impact of wind generation on the generation schedule, particularly the overall fuel cost, emissions and system security. Ummels et al. (2007) proposed an adapted unit commitment and economic

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http://dx.doi.org/10.1016/j.enpol.2013.11.065

dispatch tool for system operations in systems with large-scale wind power penetration, taking into account cost, reliability and environmental factors. A stochastic unit commitment problem is solved in Tuohy et al. (2009), where a mixed-integer stochastic optimization model (developed in WILMAR project (WILMAR, 2006)) is used on a "rolling planning" basis for generation rescheduling, as more precise wind and load forecasts are made available. In a more general framework, emissions are incorporated in the dispatch scheduling using multi-objective optimization (Muslu, 2004; Catalão et al., 2008), where different values are given to a weighting factor in the objective function in order to enforce the trade-off between fuel cost and emissions minimization. Several simulation models have also been developed for the qualitative and quantitative assessment of the effect of increased RES penetration on market prices (Green and Vasilakos, 2010; Morales et al., 2011; Sensfuß et al., 2008; Jacobsen and Zvingilaite, 2010), system operation costs and operation patterns of generating units (Jacobsen and Zvingilaite, 2010; Delarue et al., 2009; Maddaloni et al., 2009; Troy et al., 2010).

In all these works, a single market model (i.e. power pool or power exchange) as well as a single renewable technology (i.e. wind resources) is considered. In addition, all studies refer to a short- or mid-term scheduling period (one-day to one-year ahead).

In this paper, an extensive simulation analysis of the Greek electricity market for the next 7-year period (2014–2020) on an hour-by-hour basis considering five different RES technologies, namely wind, PV, small hydro, biomass and CHP, is presented. The impact of RES penetration on the electricity market operation is evaluated under two different models, regarding the organization of the Greek wholesale day-ahead electricity market: a mandatory power pool for year 2014 (current market design) and a power exchange for the period 2015–2020 (harmonization with the European "Target Model"). A detailed description of the characteristics of each market model is presented in the following section. An integrated software tool is used for the simulation of the current and the future day-ahead market clearing algorithm of the Greek wholesale electricity market.

In each case, the impact of the RES integration on the Greek electricity market is analyzed in terms of:

(a) the wholesale electricity market prices (System Marginal Prices (SMPs)),
(b) the total CO_2 emissions and generation cost,
(c) the number of start-ups and shut-downs ("cycling") of the conventional units,
(d) the profitability of all generating units (conventional and RES plants) and the total payment of the consumers for the energy withdrawal, and
(e) the RES uplift charge, imposed by the Greek State for the payment of the (usually higher than the SMP) feed-in tariffs to the RES producers.

An initial study on the subject was carried out in Simoglou et al. (2011). In that work, a yearly simulation analysis of the Greek electricity market under a single market model (i.e. the mandatory power pool) and ten different scenarios regarding the RES installed capacity was performed. In the present study, a comparison of the impact that each market model (i.e. power pool vs. power exchange) in conjunction with the anticipated large-scale RES integration has on specific indicators of the Greek electricity market in the long-term is presented. This work also provides insight on the specific measures enacted lately by the Greek State in order to alleviate the additional economic burden undertaken by the electricity consumers (through the imposed RES uplift charge in their electricity bills), so that RES producers are fully compensated according to the agreed feed-in-tariffs.

A concise description of the two electricity market models adopted in this study is presented in Section 2. Section 3 describes the software tool as well as the mathematical optimization models used for the multi-year simulation analysis. Section 4 provides relevant test results, while valuable conclusions are drawn in Section 5.

2. Wholesale electricity market models

The Greek wholesale day-ahead electricity market is currently organized as a centralized mandatory pool, where each generating unit submits a complex offer comprising an energy offer, a reserve offer and a declaration with its techno-economic data, including start-up and shut-down procedures and costs. The Market Operator (MO) solves a short-term unit commitment problem on a daily basis (also known as "Day-Ahead Scheduling" or DAS), where a simultaneous 24-hour co-optimization of energy and reserve resources is performed under a large set of unit and system constraints (e.g., unit start-up and shut-down procedures, minimum-up/down time constraints, min/max power output restrictions, ramp-rate limits, system reserve requirements, transmission limits, etc.). The DAS objective is the maximization of the social welfare (or equivalently the minimization of the total production cost minus the load utility) within the 24-h period of the next day. In fact, DAS is a non-convex optimization problem that is formulated and solved as a Mixed-Integer Linear Program (MILP) and yields the SMP and the units' energy production and reserves contribution schedule for each hour of the following day. In this model, additional payments (usually called "make-whole side payments") are also provided for the full recovery of the units' total operating (variable) cost, in case this is not covered through the day-ahead and imbalances settlement (cost recovery mechanism) (Stoft, 2002).

However, by 2015 the Greek wholesale electricity market is expected to be transformed to a decentralized market, based on bilateral trading and the operation of a voluntary day-ahead Power Exchange, in order to become compliant with the European Target Model (European Commission, 2009b). Following the current trend in most European countries, in the future Greek power exchange the participants (producers/suppliers) will submit simple energy quantity (MWh)-price (€/MWh) offers/bids for the energy they wish to sell/buy at every hour of the next day. The Market Operator (MO) will create the aggregated supply and demand curves and clear the day-ahead market on an hour-by-hour basis by solving a convex Linear Programming (LP) problem, without considering any unit operating constraints or system operation constraints.

In the power exchange case, the solution of the aforementioned day-ahead market clearing algorithm will provide only the SMP for each hour of the next day. In order to yield feasible commitment and dispatch schedules for all generating units, the MO (or the SO) will solve again the day-ahead scheduling taking into account all system and unit operating constraints already described, in the framework of a "day-ahead balancing market", in compliance with the current market structure of the most European countries and the future European Target model. Therefore, the solution of the day-ahead balancing market as an MILP model yields the units' energy production as well as all other operating results (e.g. CO_2 emissions, unit operating costs, number of unit start-ups, etc.). The involvement of each producer/consumer in the feasible schedule derived by the solution of the day-ahead balancing market is, in general, different as compared to the respective initial positions assigned according to the clearing of the power exchange. There are