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The cost of balancing a parabolic trough concentrated solar power plant in the Spanish electricity spot markets

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Abstract

This study presents a new dispatch model (SCSP) for a CSP plant based on a dynamic programing algorithm. The purpose is to investigate the cost of balancing a CSP plant in the Spanish electricity market. Results are presented for a parabolic plant in the Spanish market for years 2009, 2010 and 2011 using solar availability data at the Plataforma Solar, Andalucia, Spain. The variation of balancing cost with solar multiple (*SM*) and number of storage hours (*Nh*) is analysed and results for two different optimisation cases presented. The first uses day-ahead forecasts for both solar availability and market prices. The second uses day-ahead solar availability and within-day market price forecasts. Both cases are settled in the balancing market. Key results include that the balancing cost decreases with increased *SM* and *Nh* and that balancing costs can be 2.2% to 9.5% of the plants gross income. For all *SM* and *Nh*, balancing costs are a function of season, being lower in summer than winter driven by increased load-factor in summer. During the year Quarter 3 has a lower balancing cost than Quarter 2 due to a closer match between forecast and actual solar availability. Optimising against within-day prices costs more than with day-ahead prices resulting from more balancing energy traded at a less favourable price than day-ahead. It is envisaged that the numbers presented in this study will provide an aid to policy makers when constructing tariffs to support future CSP development.

Keywords: Concentrated solar power; Parabolic trough; Balancing markets; Spanish electricity market; Dynamic programming

1. Introduction

Concentrated solar power (CSP) has to potential to provide an enormous contribution to clean (CO_2 free) electricity supply in Europe (EASAC, 2011). A critical part of any concentrated solar power (CSP) project is securing income for the plant. In Spain, recent changes to Spanish law have significantly reduced the amount of incentive available to CSP plants (CNE, 2014, 2013, 2012). CSP plants were previously incentivised in a manner proportional to the amount of power they produced. The changes mean they can now earn market price plus a fixed incentive linked to the capacity cost and costs of operation of a standard CSP plant (CNE, 2014). This total income is designed to give a reasonable return to the project investor over the lifetime but is significantly less than was available under the previous incentive schemes. This has placed a greater emphasis on the income derived from selling power output directly to the wholesale market. In the wholesale market ordinary generators are required to forecast and then meet their electricity production. Failure to do so can result in significant costs for the plant operator. These costs are recovered by the grid operator via the balancing system.

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Since forecasting solar energy is not a certainty, the cost of balancing a CSP plant could have a significant impact on its income stream. The purpose of this paper is to investigate the financial impact of balancing a CSP plant in the Spanish electricity market.

A suitable approach to investigate balancing costs is to use a computer simulation to dispatch the CSP plant in an economic environment. Several examples exist in the literature. The dispatch of CSP plants in an electricity market environment is investigated in (Usaola, 2012). An analysis of CSP plant revenue using a linear optimisation dispatch model is provided and it is shown that the level of subsidy that was available in Spain 2012 did not incentivize full plant dispatch with thermal storage. The analysis assumes that all power is sold at the day-ahead market price and that the plant schedule is perfectly known at the day-ahead stage. In particular no correction is made to results due to balancing costs. It is noted that the subsidy level analysed is not available in the Spanish Market now (Sioshansi and Denholm, 2010) analyse the sensitivity of CSP value to several factors including optimisation period, price and solar forecasting, ancillary services, capacity and dry cooling for four CSP plants in the USA in 2005. They estimate the impact of dispatching without perfect foresight of solar availability or market prices concluding that at least 87% of the plant income is attained without perfect foresight. They use a "back-casting" technique, see (Sioshansi et al., 2009) for a detailed description, which involves used an historic dispatch, e.g. using the previous days solar and market data. This dispatch is valued against the actual outturn prices and compared to the perfect foresight case. The historic dispatch is suboptimal and results in less income. The precise details of their calculation are not given and balancing costs do not appear to be considered here. It is also noted that no price or solar availability prediction models are used in the analysis. The authors use a mixed integer linear optimisation model which is based on the Solar Advisor Model (SAM) (Gilman et al., 2008) but improves the dispatch rules (Wagner and Rubin, 2012) provide results from an economic simulation model which analyses a parabolic trough (PT) CSP with two different non-direct generation options: thermal energy storage (TES) using molten salt and a natural gas backup system. In particular they note that thermal energy storage can increase the annual capacity factor from 33% (no TES) to 55% (with TES). The levelised cost of energy (LCE) can is shown to increase with TES when 12 h of storage is required. It decreases, however, when only 1–4 h of storage is required (Wagner and Rubin, 2012) also note that a carbon price of 100–160$/MT is required to make the plant profitable at market levels and present results which stress the importance of TES. The focus is on LCE and not economic dispatch in a market environment however.

An alternative approach to the optimisation dispatch problem not yet seen for CSP plants is to use a dynamic program (Bradley, 1977). The technique is intuitive since it uses a state-space which describes all the current possible states that the plant can be in along with the possible state transitions and the cumulative effect (the Bellman equation) (Yun et al., 2011) apply such a dynamic optimisation model to the dispatch of coal plant highlighting cost savings that can be achieved when price information is input to the algorithm. The approach becomes limited if the number of state-space variables becomes large since the state-space becomes difficult to define and the computational run-time becomes large. For this reason the typical approach to CSP modelling is linear optimisation. If the number of state variables can be reduced, however, the dynamic programming approach provides an intuitive solution to the optimisation problem. It is noted that the use of a dynamic program has not yet been applied to CSP in the literature.

Two critical factors that affect the balancing of a CSP plant are the forecasts of solar radiation and market price. The uncertainty in solar energy is what drives the balancing cost fundamentally. In terms of modelling, statistical models based on time series analysis tend to be favourable for short-term solar radiation prediction (SRP). Typical errors associated with solar forecasting are quite large highlighted by the following works in the literature (Zeng and Qiao, 2013) measure the mean average and percentage errors in hour-ahead forecasts using several SRP models. Each model produces a prediction of atmospheric transmissivity which is then converted to solar power dependent on the latitude and time of day. The models analysed covered several techniques (autoregressive, neural network, support vector machines) with the results showing the best case for a typical hour-ahead mean percentage error was 15% increasing to 40% for a 3-h ahead prediction (support vector machine) (Huang et al., 2013) use an autoregressive model including a seasonal adjustment to predict hour-ahead solar radiation in Mildura, Australia. In particular they note that their model makes the error seen on cloudy days similar to that on sunny days in terms of root mean square error (RMSE) (16%) (Martin et al., 2010) present comparisons of three statistical models for 3-day-ahead forecasts of half-daily solar irradiance for different meteorological stations in Spain. They use data from the Spanish National Weather Service (AEMET). They conclude that in general neural networks based models perform best and that the error in forecasting is typically 20–30% (Lara-Fanego et al., 2012) present results for 3 day-ahead forecasts of direct normal irradiance (DNI) based on a physical atmospheric model to give global horizontal irradiance (GHI) followed by post processing of the results to give DNI. They highlight typical errors of 10% RMSE for sunny days rising to 100% RSME for cloudy days (Ohtake et al., 2012) use a similar model to forecast GHI in Japan to examine the error in a 33 h-ahead forecast. Typical RMSE's are again of order 10% for summer months up to 40% for winter months. The typical uncertainty in solar forecasting over the day-ahead to hour-ahead period ranges from about 15% to circa 50% depending on the day.