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Calculating the financial value of a concentrated solar thermal plant operated using direct normal irradiance forecasts

Edward W. Law [a,*], Merlinde Kay [a], Robert A. Taylor [a,b]

[a] School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, New South Wales 2052, Australia
[b] School of Mechanical Engineering, University of New South Wales, Sydney, New South Wales 2052, Australia

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Abstract

This study examines the effect of direct normal irradiance (DNI) forecast accuracy on the financial value of a concentrated solar thermal (CST) plant. Other factors such as electricity market regulations, plant site local climate, and operating strategy are not considered. A CST model varied over 11 combinations of solar field sizes and storage sizes is used to simulate plant operation for three forecast methods and a perfect forecast. The financial value is calculated using revenue and reserve generation payments resultant from plant operation.

Results show when the root mean square error (RMSE) of a 48-h DNI forecast is between 325 and 400 W/m^2, a 1 W/m^2 improvement increases the financial value by \$400–1300 per 6 months operation for a CST plant with solar multiple between 1.25 and 2, and storage size between 0 and 20 h. Similarly, when the mean absolute error (MAE) is between 250 and 300 W/m^2, a 1 W/m^2 improvement shows an increase of \$1000–3600 per 6 months operation. If two forecast methods have similar MAE or RMSE, then the method that tends to over-predict DNI achieves higher value. For all forecast methods, increasing solar multiple or storage size increases financial value. Financial value expressed using only revenue is overstated by 14–64% compared to using both revenue and reserve generation payments, depending on the CST plant configuration and the forecast method. CST plants with small solar fields or small storage sizes gain proportionally more from investing to obtain better DNI forecasts because more accurate forecasts help these CST plants generate more electricity from the limited solar field thermal output, and use more of the limited stored thermal energy to increase revenue instead of reduce reserve generation payments caused by forecast errors.

Keywords: Concentrated solar thermal power; DNI forecasting; Forecast accuracy; Financial value

1. Introduction

The value of a concentrated solar thermal (CST) plant can be given in financial terms by using the cash flow produced by the CST plant operating in an electricity market. This is of most interest to stakeholders who financially gain from CST plant operation, such as owners, operators and investors. Studies have calculated the cash flow by modelling CST plant operation. For example, Sioshansi and Denholm (2010) showed that higher revenue could be earned by increasing solar field size, increasing thermal energy storage (TES) size and using wet cooling instead of dry cooling for the power block. The increase in

* Corresponding author at: School of Photovoltaic & Renewable Energy Engineering (SPREE), Tyree Energy Technologies Building, University of New South Wales, Sydney, New South Wales 2052, Australia.
E-mail address: edward.law@unsw.edu.au (E.W. Law).

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financial viability by adding TES to a CST plant was also demonstrated by Madaeni et al. (2012) and Casella et al. (2014). Besides directly supplying electricity demand, a CST plant could earn more revenue by providing reserve generation (RG) or ancillary services (Sioshansi and Denholm, 2010). However, depending on the market, the total revenue may be lower than that from selling electricity (Usaola, 2012b). Overall, these studies demonstrate that plant design, operating strategy, and electricity market regulations affect CST plant financial value.

The results from these studies were achieved by optimising when to charge and discharge TES such that the revenue earned was maximised. These decisions were made by assuming perfect knowledge of available DNI or the amount of resource available for generating electricity. In reality the available DNI is not perfectly known and has to be estimated by using forecasts, which can be based on a variety of physical and statistical approaches (Coimbra et al., 2013; Law et al., 2014b). Forecast errors may prevent the maximum revenue being achieved and may even have costs attached to them, thus the value estimated in studies that assume perfect forecasts overstate the financial value.

Some studies have calculated CST plant financial value using imperfect forecasts. Results from Wittmann et al. (2008) showed that a 24-h persistence forecast outperformed two numerical weather prediction (NWP) models by consistently producing revenue within 5% of that from a perfect forecast over two consecutive days of clear sky conditions and three consecutive days of cloudy conditions. The unusually good performance of persistence for the cloudy days was attributed to the consecutive cloudy days having similar DNI profiles. Using two and a half years of data to include more weather conditions, Kraas et al. (2013) showed that a NWP model forecast incurred 47.6% lower penalty costs than a 48-h persistence forecast. Modelling results over one year of data led Sioshansi and Denholm (2010) to estimate that a 24-h persistence forecast would achieve at least 87% of the revenue earned using a perfect forecast. These studies show that different forecast methods will achieve different CST plant financial value due to the effect of forecast errors on CST plant operation. Forecast accuracy depends on how well a forecast method is able to predict changes in the local weather. The type of weather common to a location is influenced by the local climate, thus plant site also affects CST plant financial value.

This study focuses on the effect of forecast accuracy on CST plant financial value. Assessing the increase in value offered by a more accurate forecast method can justify the cost of upgrading to that method. In contrast to previous studies that only used either revenue or cost, this study presents a method that uses both revenue and cost to calculate financial value of a CST plant operated using different DNI forecast methods. The calculation method used in this study is described in the next section. A demonstration of the method is outlined in Section 3. Following that, the results and a discussion are presented in Section 4 and Section 5, respectively.

2. Financial value calculation method

The calculation method in this paper requires forecast DNI, actual DNI, electricity price and a CST model that can optimise the operation of the power block and TES. The procedure for calculating financial value is presented in Fig. 1. Forecast DNI is converted to forecast solar field thermal output by the solar field component of the CST model. Similarly, actual solar field thermal output is obtained from actual DNI. The forecast solar field thermal output and electricity price are used to optimise the operation of the power block and TES to maximise revenue. It is assumed that the optimum operation defines the dispatch targets that the CST plant commits to achieving. Actual solar field thermal output is used to determine whether the CST plant is able to achieve the dispatch targets. Generated electricity earns revenue in proportion to the amount generated and the electricity price at that time.

Over-forecasting DNI leads the CST plant operator to believe that more electricity can be generated than possible. Consequently, the CST plant may not be able to meet its dispatch target. If the CST plant fails to meet its dispatch target, then it will incur a cost of paying for reserve generation (RG) to supply the electricity that it could not generate. Thermal energy stored in TES may be used to compensate for the over-forecast error, but it may be insufficient to completely avoid RG costs.

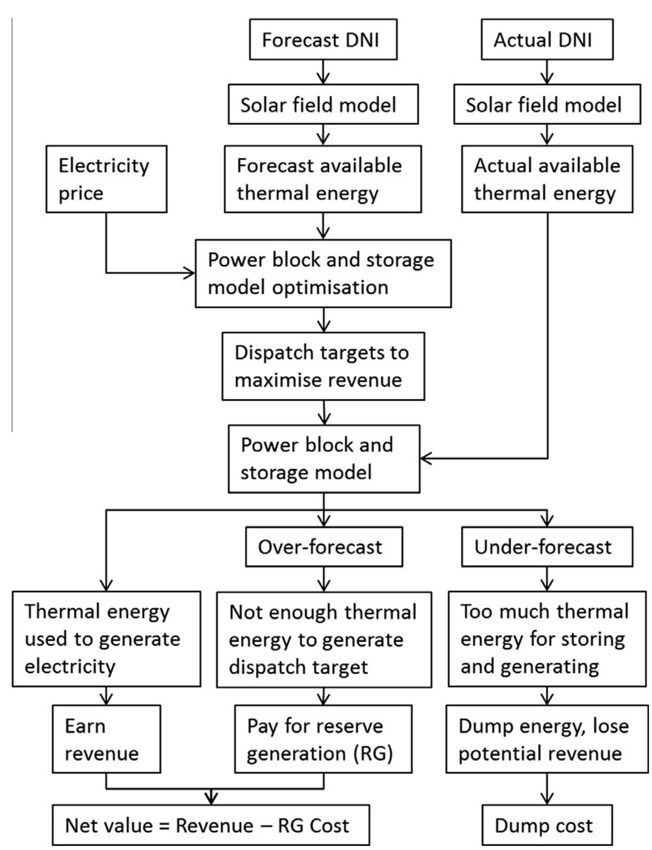

Fig. 1. Summary of method to calculate financial value metrics.