Increase the value of wind power plants through the hybridization with solar photovoltaic

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Abstract

The increasing penetration of variable renewable energy sources, such as wind and solar PV, requires these technologies to actively support power system operation through participation in day-ahead and balancing markets, including the provision of ancillary services. In this context, hybrid power plants, where wind and solar PV share a common point of common coupling and are operated as a single unit, can provide technical and economic advantages compared to standalone plants. This work focuses on the "firm capacity" that can be offered in the Portuguese balancing markets using probabilistic power forecasts, considering the hybridisation of existing wind power plants with solar PV units. Results are compared with the standalone wind power plant and feature-based indicators are also explored to assess whether dynamic selection of forecast quantiles can increase the available capacity for balancing market. Two case studies in Portugal with different levels of wind and solar complementarity are considered. Results show that hybrid power plants significantly increase the amount of capacity available for market participation from 20.5% to 66.2% relative to standalone wind power plants. Thus, hybridisation enhances the ability of existing grid assets to provide ancillary services through participation in balancing markets.

1 Introduction

Europe's energy transition is accelerating, with wind and solar photovoltaic (PV) playing a central role in decarbonisation strategies. This is reflected, for instance, in national plans such as National Energy and Climate Plan (NECP) 2030 available for almost all European countries [1]. However, the rapid growth of these technologies creates new challenges for the electricity system. Unlike conventional generation, variable renewable energy sources (vRES) depend on weather conditions, which makes their output uncertain and highly variable over time. Thus, this variability is no longer a minor issue since it can affect system reliability, increases the need for flexibility, and can lead to inefficient use of grid infrastructure [2], [3].

One way to reduce this variability is through generation complementarity, which refers to how different renewable resources can balance each other over time and location [4]. Hybrid power plants (HPPs), combining technologies such as wind and solar PV, at a single grid connection point (Pcc), provide a practical way to exploit the complementarity [5],[6]. The hybridisation of existing assets can improve output stability, optimise grid usage, and reduce expansion needs [7]. This is especially important in countries such Portugal, where renewable targets are ambitious, but grid capacity for hosting new capacity in short-term is limited. Nevertheless, the Pcc's maximum injection is a hard limit, and, therefore, overplanting capacity must be carefully sized to avoid inefficiencies with excessive curtailment [3].

Electricity market rules also increase the importance of properly addressing the intrinsic variability associated with the vRES generation. In most European electricity markets, participation in the day-ahead market (DAM) requires power forecasts 12-36 hours in advance. These forecasts rely on numerical weather prediction (NWP) models and, more recently, in machine-learning NWP [8]. Machine learning is also used in post-processing to convert weather data into power generation forecasts. Despite these advances, forecast errors remain significant, leading to imbalance costs and jeopardising vRES' market revenues. Probabilistic forecasting offers a partial solution by representing outcomes as distributions rather than single values, improving decision-making under uncertainty. While several studies for individual technologies are available, the application of probabilistic power forecast to hybrid wind-solar systems remains limited, despite evidence that hybridisation can improve forecast accuracy and, consequently, their market value [9], [10].

As the merit-order effect associated with low marginal-cost vRES intensifies, participation in balancing markets becomes increasingly important for revenue diversification and can also contribute to power system robustness and stability [11]. Nevertheless, as a last-resort resource for the transmission system operators (TSO), these technologies must demonstrate compliance with strict reliability requirements, namely, that committed capacity can be delivered with a high level of certainty [12]. In this context, this work focuses on the *firm capacity* that can be offered in balancing markets using probabilistic power forecasting, considering the hybridisation of existing wind power plants with different levels of solar PV integration. Results are compared against a standalone wind power plant.