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## Price development and bidding strategies for battery energy storage systems on the primary control reserve market

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### Abstract

Decreasing prices on the German primary control reserve (PCR) market lead to an uncertain economic situation for battery energy storage systems (BESS) providing PCR. In a simulation-based approach, which takes into consideration application-specific aging, an economic assessment of a 1.5 MWh BESS providing PCR is conducted. Different bidding strategies for PCR auctions have been developed and their impact on revenues and battery aging has been investigated. Furthermore, following an option value approach, we analyzed how different PCR price paths and the time of investment affect the economic feasibility of BESS providing PCR.

The results show that the choice of strategies developed in this paper do not have a substantial influence on revenues and battery aging. However, the development of PCR market prices and battery system costs is crucial for the economic feasibility of BESS providing PCR. Investments come with a high risk due to the volatility of PCR market prices and the uncertainty of future battery system prices.

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*Keywords:* Battery energy storage system; primary control reserve; economic assessment

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## 1. Introduction

Stabilizing the electricity grid is a major challenge for system operators, particularly with a growing share of intermittent renewable energy sources feeding into the grid. Since the electricity grid is not capable of storing energy, control reserve is required to balance feed-in and consumption. Primary control reserve (PCR) is the product with the fastest response time and the shortest deployment period in the interconnected grid of the European Network of Transmission System Operators (ENTSO-E) Regional Group Continental Europe. PCR is tendered by the responsible transmission system operator and traded on separate markets with specific regulatory frameworks.

This paper focuses on the German PCR market, which has undergone a dynamic development in recent years. This includes the integration of neighboring countries and an increasing share of stationary battery energy storage systems (BESS) providing PCR. In 2016, a rapid drop in PCR capacity prices could be observed. This development raises the question whether providing PCR is a sustainable business model for BESS operators.

We aim to investigate the economic feasibility of BESS providing PCR in the given framework, focusing on bidding strategies of BESS operators in PCR auctions and on future price paths for PCR capacity prices. In order to calculate revenues and losses, a model has been developed to simulate BESS operation and aging. Different bidding strategies and price paths are implemented to analyze their respective impact on economic feasibility.

### Nomenclature

BESS	battery energy storage system
$CAP_{\min}$	power plant minimum load (MW)
$CAP_{\text{PCR}}$	amount of PCR capacity provided (MW)
$C_{\text{BESS}}$	battery capacity (MWh)
$c_{\text{var}}$	variable costs (€/MWh)
E	energy (MWh)
PCR	primary control reserve
$p_{\text{DA}}$	price on the day-ahead market (€/MWh)
$p_{\text{max}}^{\text{FC}}$	maximum forecast PCR price (€/MW)
$p_{\text{min}}^{\text{FC}}$	minimum forecast PCR price (€/MW)
$p_{\text{wa}}^{\text{FC}}$	weighted average of forecast PCR prices (€/MW)
$p_{\text{PCR}}$	price on the primary control reserve market (€/MW)
$p_{\text{PCR},0}$	price on the primary control reserve market in the base year (€/MW)
$p_{\text{PCR},s}$	price on the primary control reserve market at saturation level (€/MW)
SoC	state of charge (%)
$\Delta E_{\text{DU}}$	energy exchanged due to deadband utilization (MWh)
$\Delta E_{\text{OF}}$	energy exchanged due to overfulfillment (MWh)
$\Delta E_{\text{PCR}}$	energy exchanged due to PCR provision (MWh)
$\Delta E_{\text{SC}}$	energy exchanged due to self-consumption (MWh)
$\Delta E_{\text{ST}}$	energy exchanged due to schedule transactions (MWh)
$\lambda$	exponential decay constant (-)
$\eta_{\text{ch}}$	charging efficiency (-)
$\eta_{\text{dis}}$	discharging efficiency (-)

#### 1.1. Literature review

Providing PCR has been found to be a high-value application field for stationary BESS owners [1]. Furthermore, using BESS instead of conventional power plants is a promising option to reduce environmental impacts of PCR provision [2]. In the literature, different aspects of this subject are investigated. A number of publications deal with

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