Mechanical Engineering Dissertation Defense

Techno-Economic Analysis of Solar PV and Energy Storage for a Carbon-Neutral Grid in Arizona

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Abstract

Achieving a carbon-neutral grid in Arizona requires careful integration of renewable generation and energy storage. While extensive research has examined renewable integration, and energy storage sizing, gaps remain in understanding the time-of-use storage requirements and their impact on cost. This dissertation addresses these gaps by developing a model that utilizes hourly electricity demand and weather data to conduct a utility-scale analysis that determines the inter-annual storage requirements with a least-cost portfolio optimization. Results show that flat, fixed-tilt PV minimizes system cost and storage capacity. The decomposition of storage requirement by time-of-use analysis reveals that daily minimum and seasonal peak storage supply more than 95% of storage discharge hours, while multi-day, used for ~5% of the year drives over half of the total capacity needs. Wind integration reduces daily minimum and multi-day storage needs by up to 48% but has limited impact on seasonal peak storage due to high electricity demand and lower wind speeds. A least cost optimization identifies that pumped hydro energy storage and compressed air energy storage provide ~30% of the initial storage needs at an average marginal cost of approximately USD 0.10/kWh, Lithium-ion batteries provide the bulk of the requirements at ~62% at USD 0.22/kWh, and hydrogen limits the multi-day costs at USD 0.36/kWh. Direct air capture is not selected as it exhibits a high levelized cost of storage of USD 0.45/kWh. Across the 2019–2023 period, pumped hydro and compressed air consistently provide approximately 30–35% of total storage hours, while lithium-ion batteries supply 58–64%. Hydrogen contributes between 6–9% of storage hours, with the range upon the frequency and depth of the multi-day events. Event-based DR targeted at multi-day events can substantially reduce the required storage capacity but would require the utilities to at least double the required DR capacity to 500 MW. The current capacity and energy charges paid out to consumers result in a levelized cost of demand response of USD 1.21/kWh, which is 4 times higher than the highest cost of storage in the portfolio highlighting how significant reductions in capacity and energy charges are needed.

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