Competitive Energy Storage And The Duck Curve

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Power systems with high penetrations of solar generation need to replace solar output when it falls rapidly in the late afternoon – the duck curve problem. The traditional solution to this problem would be to build and use more gas turbines or combined cycle plants that can increase output rapidly. However, this is inconsistent with the goal of reducing carbon dioxide emissions. As the costs of storage have declined, storage has emerged as a potentially attractive, carbon-free alternative way of offsetting diurnal declines in solar generation. This paper considers whether competition can be relied upon to provide an efficient supply of storage in this context.

I consider a Boiteux-Turvey-style model of an electric power system with alternating periods of two types, labeled daytimes and night-times, corresponding roughly to the duck's back and its neck. Renewable generation has positive, stochastic output only in daytime periods. Gas generation, which, for simplicity, stands in for the whole suite of dispatchable generation technologies, is assumed to be available in both daytime and nighttime periods. Short-term storage can be installed at a constant cost per unit of capacity, and storage involves a constant fractional round-trip loss of energy. Demand in both days and nights is stochastic, constant within periods, and perfectly inelastic. Price is assumed to rise to the value of lost load if demand exceeds available supply.

Under constant returns, competitive generators' operating rules are simple: produce if and only if market price of energy is greater than or equal to marginal cost. In general, optimal charging or discharging of storage under competition depends on the current energy market price, the amount of energy in storage, and expectations regarding future energy prices. In general, it does not seem possible describe the behavior of competitive storage suppliers when storage is not fully discharged in each nighttime period without additional assumptions or resorting to numerical methods. In the context of the duck curve, however, at least in the near term, imposing the restriction that storage is fully discharged in each nighttime seems reasonable. Doing so leads to three possible regimes relating the marginal cost of gas generation to expected nighttime prices. The first-order conditions for minimizing expected total cost in each regime are exactly the break-even conditions for long-run competitive equilibrium. Thus all expected cost minima are long-run competitive equilibria.

It has not been possible to prove that the corresponding Hessian is always positive-definite, but its diagonal elements, the own second partial derivatives of the expected total cost function are always positive. Thus the long-run equilibrium value of storage capacity always minimizes expected system cost conditional on generation capacities.

As noted above, the formal analysis in this paper makes the usual assumption that the energy price rises to the value of lost load in shortage conditions. If the energy price is capped below the value of lost load, however, this analysis implies the existence of a "missing money" problem for storage, exactly like the problem that has led to the proliferation of "capacity mechanisms" to supplement energy market revenues in order to provide incentives for adequate investment in generation.

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