A game-theoretic framework to investigate the conditions for cooperation between energy storage operators and wind power producers

S. Bhela, K.-S. Tam

Bradley Department of Electrical and Computer Engineering, Virginia Polytechnic Institute and State University, MC 0111, 1185 Perry St. / Room 302, Blacksburg, VA 24061, USA
E-mail: sidbhela@vt.edu, ktam@vt.edu

Abstract:

Energy storage, has widely been accepted as a means to provide capacity firming service to renewable sources of energy due to its capability to quickly start and shut down and its ability to have flexible ramping rates. Lithium Ion batteries in particular are of interest as their production cost is expected to significantly decrease over the next few years. In addition, Li-Ion batteries have high efficiency, high energy density and high cycling tolerance. These batteries are also used in electric vehicles whose penetration is expected to grow rapidly in the coming years.

The social benefit of energy storage to provide energy balancing service to renewable producers is evident, especially in the context of a micro-grid where deviations from distributed generation sources can be handled locally. However, co-operation with renewable producers may not be automatically guaranteed and would depend on the amount of revenue generated by balancing such deviations. Storage may derive more benefit from choosing to operate independently. Balancing wind deviations would take capacity away from providing other high value services to the micro-grid community such as arbitrage and regulation service.

The decision to enter the market and balance deviations for the wind producer is highly intertwined with the strategy adopted by the wind producer. Interactive problems in which the outcome of a rational agent's action depends on the actions of other rational players are best studied through the setup of a game-theoretic framework.

A case-study is presented here using wind and electricity market data for a site in west Texas. Historical data is used to calculate expected pay-offs for the month of January. The columns in the following table are the available strategies for the wind producer and the rows are the available strategies for the energy storage. There are four possible combination of strategies, which are discussed next:

WIND / **STORAGE**	**CO-OPERATION**	**NON-COOPERATION**
CO-OPERATION	**$ 707** **(Case 1)** **$6,988**	$195 (Case 2) $8,514
NON-COOPERATION	$2,108 (Case 4) $5,422	$195 (Case 3) $4,870

Table 1.1 – Payoff Table

The pay-off table provides the net revenues of the wind producer in the upper right corner and the net revenues of the energy storage in the lower left corner of each cell. Note that revenue from Production Tax Credits (PTC) is not included for the wind producer.

Case1:

In this case the wind producer and the energy storage play co-operative strategies to act as one entity and deliver the promised power output. The energy storage receives imbalance payments (fixed percentage of day-ahead market price) from the wind producer for giving priority to absorbing wind deviations – any remaining capacity is used for arbitrage, regulation service and absorbing load deviations and is paid by the utility. In addition to the imbalance payments to the energy storage, the wind producer may pay additional fines to the utility.

Case2:

In this case the wind producer chooses a non-cooperative strategy and pays hefty penalties (fixed percentage of day-ahead market price) to the utility. The energy storage indirectly co-operates by absorbing wind deviations through the utility, but gives preference to absorbing load deviations first - any remaining capacity is used for arbitrage and regulation service. Payment for imbalances (fixed percentage of day-ahead market price) is received through the utility instead of the wind producer. Penalty charged by the utility is assumed to be higher than the penalty charged by the energy storage entity.

Case3:

In this case both the wind producer and the energy storage choose non-cooperative strategies. The wind producer pays hefty penalties to the utility just like the previous case (Case 2). The energy storage chooses to operate independently by providing services to balance net deviations (load + wind deviations) - any remaining capacity is used for arbitrage and regulation service. Storage does not receive imbalance payments in this case.

Case4:

In this case the storage chooses to play a non-cooperative strategy by operating independently like the previous case (Case 3). The wind producer knowing that the storage will choose not to co-operate curtails its output when overproducing to reduce the imbalance on the system.

As evidenced from the pay-off table there is only one pure strategy Nash equilibrium (Case 1). The co-operative strategy for the wind producer strictly dominates its non-cooperative strategy. Similarly, the cooperative strategy for the energy storage strictly dominates its non-cooperative strategy. As both players would choose to play a co-operative strategy irrespective of the strategy chosen by the other player, the Nash equilibrium points to Case 1.

It is clear that in a market where penalties are imposed on any wind deviations both players would choose to co-operate with each other. Markets in which no imbalance penalties are charged shifts the equilibrium to a non-cooperative state. Therefore, imbalance penalties on both overproduction and underproduction is a necessary condition for co-operation between energy storage operators and wind producers.