OPTIMIZATION OF WIND AND STORAGE DISPATCH FOR ENHANCED MARKET OPPORTUNITIES

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Overview

Over the last decade, increase in energy need, innovations in energy generation technologies, and environmental concerns along with changes in regulatory arenas have led to a worldwide push toward renewable energies such as wind. Nowadays, wind power has proved to be among the most fast-growing electric energy sources [1]. The world wind energy capacity reached 318,529 MW by the end of 2013 [2]. Still, doing away with conventional "unclean" energy sources on behalf of renewable energy sources remains a dream. In fact these environment-friendly sources are intermittent and hardly predictable. Thus, even with a rapid development these recent years, wind power generation is handicapped by its undispatchability and unschedulability [3]. Because wind power is not dispatchable, there are lots of problems associated to wind energy integration to the grid. To prevent grid instability, the most common antidote proposed in the literature is to couple wind farms to electric energy storage (EES) systems in order to smooth out wind power intermittency and adjust it to the demand cycle. Energy storage can guarantee to some extent the availability of a portion of the produced wind power within a given timespan [4].

However, the current energy storage technologies on average require high capital and operating costs, which make wind farms quasi completely dependable on subsidies [5]. In these conditions, any financial or economic crisis may represent a major threat for wind farm owners who are left with a passive participation in the energy market. Indeed, due to the fact that they cannot schedule their asset's output, they are forced to even generate at negative prices sometimes; they cannot benefit from price spikes as conventional generators. To offset the high storage implementation cost and increase market opportunities in order to alleviate their dependency on subsidies, wind farms need an optimal system dispatch model able to schedule the EES charge/discharge cycles. The value of a power plant being based not only on its energy capacity but also on its reliability, an optimal scheduling model will enable wind farms coupled with EES to increase their marketability.

Energy storage sizing and scheduling has received a lot of attention and a few researchers have addressed it from different standpoints depending on their targets. Mainly, two approaches are usually considered: solution by direct calculation and solution by optimization [6]. This paper concentrates on the optimization approach of the battery sizing problem. It presents an inventory modeling approach to the EES charge/discharge cycle scheduling problem in the context of a grid-connected wind farm. We assume known the real time market price forecast, the day-ahead market price and wind turbines output power forecast.

Methods

In the adopted energy system configuration, the ESS undertakes two-way communication with the bus between the wind energy generation units and the energy market (grid). When optimal, the storage system is charged either by the wind power or the grid, or discharge energy into the market. The optimization model receives the wind energy output hourly forecast a day-ahead, the day-head market hourly prices, the real-time market prices forecast and the storage system parameters such as the capacity S, the charge Rate R_i, the discharge rate R_o and the roundtrip efficiency η. Taking into account the charge/discharge and capacity limits and the market information along with the wind farm's expected production, the model provides a policy with regard to the bids into the market on an hourly basis and the consequent charge and discharge decisions that are susceptible to ensure effective delivery in the time frame set. The main concern of the wind farm owner being how to find the optimal policy as to how much energy to bid for at a particular time period in order to maximize his revenue each and every day, we adopt in this paper a 24-hour horizon base stock inventory model [7]. the recursion equation is given by equation (1).

$$\theta_t(x) \triangleq maximum_{\mu t}\{p(t).(w_t-\mu_t).[\Gamma(w_t-\mu_t)]+c(t).(w_t-\mu_t).[\Gamma(\mu_t-w_t)]+\theta_{t+1}(\eta.(x+\mu_t))\} \quad (1)$$

where x is the useful charge level (state of charge at time t), $p(t)$ is the price of electricity at time t, w_t is the wind energy output available in period t, μ_t is the charge or discharge amount in period t (positive for charge and negative for discharge), Γ is the step function, $c(t)$ is the cost of electricity in period t (what it would cost the wind farm to buy a unit of energy from the market), η is the storage system's efficiency coefficient, $\theta_t(x)$ is the cost function assuming we have a charge level x in period t, θ_{t+1} is the cost function in period t+1. We then solve the revenue maximization problem as a DP using Matlab.

Results

The typical outcome of the inventory model presented in the previous section is a policy table which advises on the best action to take at a particular time for all possible states of the system. For the wind farm and storage dispatch problem, the model's output is a bid and charge/discharge schedule assuming a perfect knowledge of system state throughout the entire horizon. We present in this section some simulation results using data from the NYISO region, zone E. We consider a hypothetical 100 MW wind farm located in the NYISO region, zone E. This plant is assumed to have a 100 MWh storage system, a charge/discharge rate of 40 MW and a start-up charge level of 6 MWh. Figure 1 shows a 1-day optimal operation schedule. The farm operator is encouraged to buy energy from the market for storage in addition to the wind generation available and resell it for the next couple hours. The beauty of this approach is the ability given to the wind farm to reliably commit a day-ahead to generate a certain amount of electricity using the decision making tool proposed in this work. The added value of this model is unquestionable since for this particular day, the optimal dispatch raises the wind farm's revenue from $7,280 to $25,203.

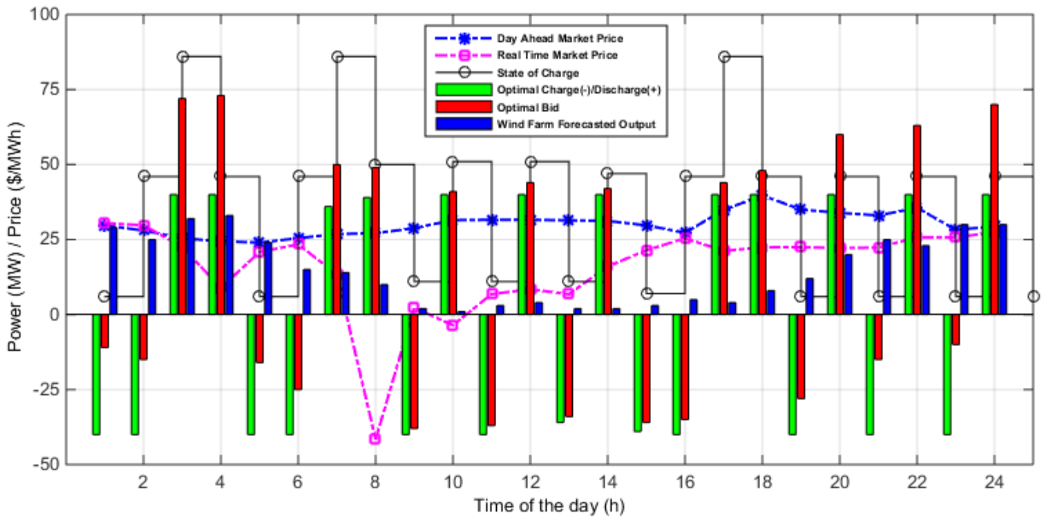

Fig.1 24-hour optimal wind energy and storage dispatch– NYISO Zone E

Conclusions

The energy industry is at the dawn of a lasting revolution. Its future is intrinsically linked to the level of renewable energy penetration. And this penetration level depends on how viable we make these energy sources. This paper proposed a tool that can help hedge wind farms undispatchability and unschedulability which in the long run risk can jeopardize the energy revolution. The configuration, basis of our study, couples a grid connected wind farm to an electric energy storage system. We adapt inventory modeling used in supply chain management to the battery charge/discharge problem and used dynamic programming to solve it in Matlab. Based on the forecasted price signals (DAMP and RTMP) and wind power, we scheduled the battery operation that maximizes the wind farm revenue, buying and selling when appropriate. The results show a substantial increase in revenue which can somewhat offset the high battery cost. In future work, we will include forcast errors, storage scales and related costs in our analysis for more accurate policies in wind energy integration into the grid.

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