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Dispatching intermittent wind resources for ancillary services via wind control and its impact on power system economics

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ABSTRACT

This paper focuses on assessing the effectiveness of wind control methods used to address the economic issues associated with higher penetration of variable (wind) generation. Two different wind control methods were implemented, namely maximum power limitation and delta control. Production costing simulations were done on IEEE 24 bus system with three wind farms, across different wind penetration levels to evaluate the impacts of wind control methods. Wind farms were allowed to participate in the ancillary service market while implementing the variable delta control. Results showed that these control methods have the potential to allow wind farm provide regulation or significantly lower regulation requirements, and reduce the overall production cost of the power system.

1. Introduction

The Department of Energy 20% by 2030 plan is increasing the amount of wind projects across the nation. In 2006 the installed wind capacity in the US was about 12 GW. By 2010 this number had grown to 40 GW [1]. This growth can be contributed to the Federal Production Tax Credit (PTC), state renewable portfolio standards, and the favorable economic and environmental characteristics of wind energy compared to other forms of energy [2]. However, increasing penetration of wind in the energy market creates more need for ancillary services, specifically regulation services due to the high variability and uncertainty in the predictions. These fluctuations also impact the other generation units that were not designed to operate under high variability conditions and therefore increase their maintenance costs.

There are many solutions available to mitigate variability issues, including energy storage [3], demand control, fast responding combustion turbines, and wind control; and each of them have to be assessed for their economic value and grid profitability. This paper examines the impacts of wind control on system ancillary service requirements and costs associated with energy and ancillary service production under three different system scenarios:

1. Increasing wind penetration
2. Wind controlled for energy and ancillary services
3. Presence of storage technology

Since 2011, Mid-continent Independent System Operator (MISO) has been requiring wind farms to register as Dispatchable Intermittent Resources (DIR). This allows wind and other DIRs to fully participate in the energy market, while increasing operational efficiency (i.e., dispatching wind farm in the energy market helps in managing congestion) and market transparency [4]. In addition to providing energy, wind farms have the ability to also provide the ancillary services, given that there is sufficient wind potential and the proper controlling equipment is installed. Therefore, this research will also help to determine if wind control is an effective way to provide ancillary services or alleviate their need, and quantify the economic benefits of doing so for the wind farm and the grid.

2. Wind control methods

Most wind farms are operated based on maximum power point tracking (MPPT) control method, which controls the turbine so that at any given moment it extracts maximum electric energy from the wind resource. Wind farms with conventional MPPT control are creating a need for increased ancillary services and complicated real power control strategies [5] due to the variability in wind speeds that result in increases and decreases in real power. These

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ancillary services can be divided into contingency reserves and regulation reserves. Contingency reserves can be further divided into spinning and non-spinning reserves [6]. In the absence of fast responding/flexible resources, conventional generators have to supply ancillary services, and they incur cycling costs due to the stress and the consequent damages to auxiliary components, boiler, turbine, and steam lines [7]. Further increases in installed wind capacity would require the industry to move away from using the MPPT control, and to a system that gives utilities more control over the power that is being generated from the wind farms.

Kristoffersen detailed the different methods used to control active and reactive power for the Horns Rev Offshore Wind Farm, in Denmark [8]. Through absolute power limitation, balance control, power rate limitation and delta control this offshore wind farm was able to adjust the power production as needed. Being able to adjust the power production as needed provides ramp-down capability if the turbine is producing an excess of energy, and ramp-up capability if the turbine is generating below its maximum power point. Such control strategies have the potential to reduce the variability, and consequently reduce the ancillary service needs and the associated costs. In the past, blade pitch and torque control have been used to address regulation and disturbance rejection on the power grid [9]. These control techniques were used to optimize maximum energy capture while operating below rated wind speeds. Howland et al. used the power rate limitation method to alter the wind power ramp rates in order to achieve reduction in wind variability and regulation requirements [10].

In this paper the focus is not only in reducing the need for ancillary services by controlling the wind output which is usually modeled as negative system load, but in employing the wind control method to enable wind generation bidding in energy and ancillary markets. Though wind farms face the risk of being penalized for real-time deviations from their offers, the ability to dispatch wind in the real-time market is aided by the fact that wind forecast errors significantly decrease with a shorter time horizon [11].

In this paper, wind control methods based on maximum power limitation and delta control [8] are implemented using a 48-h production costing program. Maximum power limitation involves limiting the peak point of a wind farm at certain hours, which should lower the need for regulation in conventional generators. Delta control involves producing and offering energy quantities lower than the wind forecast by a pre-decided amount "*delta*". If a wind farm is able to offer *X* MW of wind in the energy market, a constant delta control allows them to offer (*X* MW−*delta* MW). In this paper, we implement a variable delta control strategy, where the "*delta*" MW is decided dynamically by the hourly dispatch program such that wind dispatch is optimized for energy and regulation service commitments based on system conditions and prices. This could lower the cycling costs of conventional units and the total production cost of the system without causing a significant drop in wind farm's energy revenue by compensating them for their output control from both energy and ancillary markets.

3. Experimental methods

A production cost program developed using MATLAB with the Tomlab optimization suite was used to perform the analysis. The analysis was done on the IEEE 24 bus Reliability Test System (RTS), shown in Fig. 1, for different control regimes and different wind penetration levels. Three wind farms are located at buses 17, 21 and 22.

The objective is to minimize energy production costs, ancillary service costs and load-shed penalty costs. The constraints imposed

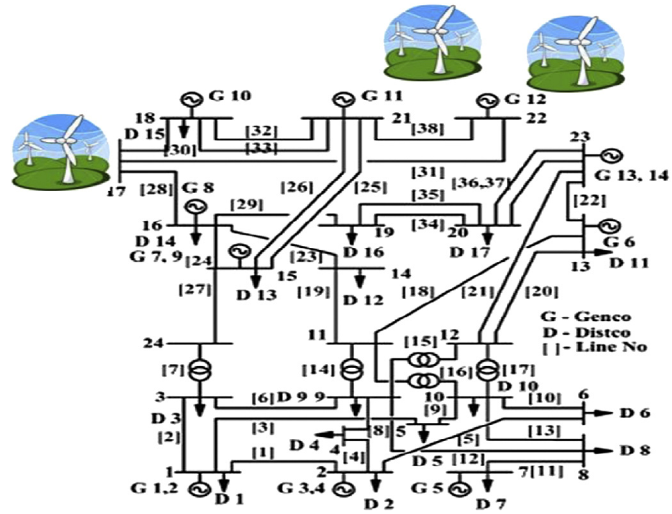

Fig. 1. IEEE RTS 24 bus system.

within this optimization problem are as follows: power balance, wind availability, transmission line limits, generation power and ramp rate limits, and DC load flow constraints. Wind energy was limited by hourly forecast based on historical data. Fig. 2 shows the system load, wind and net load over 2880 min (48 h) for 40% wind penetration. Based on the net-load variability data, the hourly regulation requirements were estimated [12], and unit commitment and economic dispatch were performed. The production costing program is designed to always match the generation to hourly energy and ancillary service requirements needed to meet the net load variations, subject to transmission limits.

In the program wind control is being modeled in two ways:

1. *Maximum power limitation*: The wind farms are subjected to maximum power limitation. From a section of the 48-h forecast with high variability, an upper bound is determined for power production. Everything below this cap is offered into the energy market, and the rest can be offered into the ancillary services market.
2. *Delta control*: Delta control is implemented in the program in two ways. A constant delta control limits wind production at every instance by a fixed amount. Variable delta control

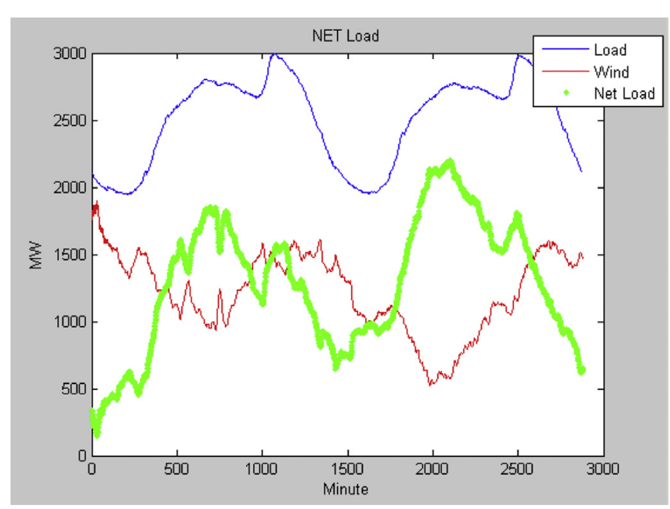

Fig. 2. Load, wind, and net load for 40% wind penetration.