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Demand response and pumped hydro storage scheduling for balancing wind power uncertainties: A probabilistic unit commitment approach

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ABSTRACT

Wind generation with a low capacity factor and uncertain nature poses many challenges in grid integration and secure operation of power system. This demands larger quantities of balancing services known as Ancillary services (AS), at cheaper cost in short notice of time. Operating Reserve is a major portion of Ancillary service that can balance the power system with wind integration uncertainties. Utilizing Energy Storage and Demand Response as Operating Reserve, maximum wind energy integration can be achieved in a constrained power system. This paper presents the participation of Pumped Hydro Storage (PH) and Demand Response (DR) as Operating Reserve Ancillary services (ORAS) to mitigate the issues related to wind power integration into the system. Simultaneous scheduling of PH and DR in Energy and Ancillary service markets with wind uncertainties has been attempted by solving Probabilistic unit commitment problem using Lagrangian Relaxation (LR) method. Various cases studied by emphasizing on optimization of operating cost and cost of Operating Reserve are presented and results are found to be encouraging.

Introduction

Restructuring of power systems has facilitated competition among market participants. Federal Energy Regulatory Commission (FERC) in its order 888 has defined the significance of Ancillary services in restructuring for protecting system security and also ensuring reliability. A separate market for Ancillary services is still at its inception state around the world. Some of the systems like PJM, NYISO ISO (Independent System Operator), MIDWEST ISO, CALIFORNIA ISO, and ERCOT ISO have initiated separate market for Ancillary services to be dispatched along with Energy. Load following, Reactive power, Voltage control and Black start capability are some of the services that these ISO's are looking forward to design, which are proven for their efficiency and compatibility. These ISOs are dealing with some of the above mentioned Ancillary services. Reserve is one such Ancillary Service which these ISOs schedule in their markets. PJM schedules Reserve as 1% of the peak load and 1% of the valley load. NYISO sets reserve requirement based on weekday or weekend, hour of day, and season. MIDWEST ISO schedules the reserve based on conditions that prevail before Day-ahead market closes. CAISO uses a fixed amount Energy as up and down reserve to adust the disturbances in load, generation schedules. ERCOT the largest wind integrated ISO in United States, sets the reserve based on usage for 30 days of same month of previous year and also considers adjustment based on wind capacity.

As power markets are looking for cheaper and cleaner renewable energy resources to substitute the needs of consumers, wind energy has become an answer to such needs. However, wind integration poses many challenges to the market operators due to its variable and intermittent nature. Uncertainty in wind prediction makes it difficult for the utilities to forecast and control the output of wind generation and also large reserve capacity is necessary in case of uncertainties or non-availability of the wind turbine unit. To fulfil the stability requirement of the system, varying wind generation over a small period of time can be balanced by adjusting generation from thermal generators. As the ramping rates of the thermal units are limited, the system requires more flexible means of meeting the variations of wind. Such flexibility will be provided by Ancillary service mechanism. This also has concern in the markets with reference to payments towards such services. By properly scheduling Energy Storage mechanisms and Demand Response along with thermal units, minimum payments to the Ancillary services can be achieved while integrating wind energy. Demand Response is defined as the change in end user consumption based on change of electricity price, or incentives paid to customers for lowering the demand during peak hours. [1] proposed a

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scenario generation and reduction techniques to asses probabilistic reserve requirement with priority list based unit commitment with integration of larger quantities of renewable energies. A two stage Security Constraint Unit Commitment (SCUC) for reconfigurable networks is proposed in [2] to improve system flexibility and also to clear Energy and Ancillary markets simultaneously. [3] has proposed a two-stage robust unit commitment method to address incorporating uncertainties in system parameters into UC problem. [1,2] proposed integration of wind uncertainties into the grid by solving a unit commitment problem. To balance the uncertainties of wind energy generation a probabilistic strategy is proposed in [4] to calculate system reserve requirement over a year. In order to incorporate wind and load uncertainties for reducing total energy cost and emissions [5] used a scenario generation based Dynamic Economic Emission Dispatch method, which is solved by using Particle Swarm Optimization technique.

Traditionally, Energy Storage System (ESS) like Pumped Hydro (PH) unit is used to stabilize the mismatches between demand and generation. However, PH units can also bring balance in wind integration uncertainties by providing load following operating reserve Ancillary service to the grid. A price based Unit commitment model is proposed in [6] to schedule pumped hydro units and wind energy in day-ahead market. In [7] unit commitment, is attempted using a stochastic dynamic programming by considering wind uncertainties. Operating cost is minimized by optimal commitment and storage decisions. Total operating cost, wind curtailment and corrective action cost minimization is presented in [8] by using stochastic security constrained unit commitment. Through a stochastic unit commitment based solution [9] tried to incorporate grid scale energy storage to asses energy and operating reserve payments. [10] has assessed the effectiveness of Energy storage mechanisms in reducing the payments to operating reserve in systems containing high variable sources.

Due to high investment cost associated with Energy storage system, it is likely that providing reserve solely by them is not a feasible solution. As a result evaluating demand-side management strategies to assist reliable integration of wind resources is gaining a lot of importance. The Demand Response (DR) programs allow consumers to adjust their electricity usage according to the operator requests to handle the intermittency of wind generation. In [11] authors have designed and evaluated market clearing strategy for the exchange of DR in restructured markets by using walrasian auctions. Minimization of Operating cost and ramping cost to schedule hourly demand response is considered in [12]. In [13] a stochastic mixed integer programming problem is presented to schedule reserve offered by Demand Response in wholesale electricity market. [14] presented an implementation of real time electricity pricing and Demand Response to support integration of renewable energy generation. [15] proposed a stochastic SCUC to schedule hourly operating reserve due to uncertainties in load and wind generation. [16] proposed a robust unit commitment to reduce Average Locational Marginal price and price volatility under demand response uncertainty.

Different methods in literature mainly oriented towards reducing wind integration uncertainties with scenario reduction based techniques into unit commitment model. They have considered Energy storage or Demand response to reduce these uncertainties. Ancillary mechanism is not much been looked into to address the wind uncertainties.

In the present paper wind uncertainties are modelled using weibull PDF method and a LR method is used to solve probabilistic Unit Commitment (UC) methodology for optimal scheduling and dispatch of wind and thermal generating units along with reserve in Ancillary service market. Reserve is provided by Pumped Hydro and Demand Response for a 24 h market schedule. The proposed UC minimizes operating costs by optimal unit commitment and optimal usage of Ancillary services. Case studies are presented with 3 and 10 generator systems to verify the proposed model. This study also considers the intermittency in wind forecast.

The paper is organized as follows: Section 'Introduction' presents introduction and literature survey. Section 'Modeling of uncertainties in wind Energy forecasting' describes modelling of wind energy forecasting. Section 'Mathematical modeling' deals with the problem formulation considering energy and operating reserves for a wind integrated thermal power system. Section 'Lag rangian relaxation approach for unit commitment' gives the solution formation by LR method, Section 'Case study' presents outcomes of the work and discussions. Finally, Section 'Conclusions' provides contributions of the work with concluding remarks.

Probabilistic unit commitment problem presented in this paper gives the ISO a better source to make the right judgement to optimize the Ancillary services usage in the system. The problem solved in this paper also gives complete objective of a power system which is planning to incorporate Demand Response, Energy Storage and wind energy into their grid. Running Unit commitment for all Scenarios of wind energy is not feasible due to computational burden to the system operator. Therefore, the probabilistic techniques with a worthy accuracy and a tractable calculation are required for the framework on which this article concentrates on.

Modeling of uncertainties in wind energy forecasting

The issues in wind integration are wind variability and uncertain nature of wind speed. Forecasting of wind speed plays a vital role in the large scale wind farms integration. However, with wind integration, requirement of Operating Reserve and Voltage Control increase. So estimators need a better method to estimate wind profile. Weibull probability density function (PDF) [17] has a better accuracy in wind speed prediction. In this paper, to assess the operating reserve requirement due to wind power uncertainty Weibull PDF method is used. The historical hourly wind speed data is taken from Midwest ISO region. [18,19] provide a detailed formulation of wind prediction by Weibull PDF method. The mean velocity value for the data period in Midwest ISO is found to be $v_{mean} = 6.74$ m/s weibull factor $c = 7.70$ m/s and $k = 2.63$. Fig. 1 shows the wind speed distribution of Midwest ISO using Weibull PDF method.

Dewind D8/80 (2000 kW) wind turbine is considered in this studies. The design parameters like cut-in, rated and cut-out wind speeds are considered to be 3 m/s, 15 m/s, and 26 m/s, respectively. Weibull factor c for Midwest ISO is considered in modeling wind output from a wind farm. The wind farm consists of several Dewind D8/80 (2000 kW) wind turbines. Fig. 2 shows the wind power curve of the considered wind turbine. The Rotor diameter of the turbine is 80 m and capacity factor is 28.2%.

Mathematical modeling

Unit-commitment is to schedule the generation, while fulfilling the load demand and minimizing net operating cost. The UC can be classified into Probabilistic UC (PUC) and Robust UC (RUC). The major difference between these two is that, PUC optimizes the system operational cost, while RUC minimizes system operating cost and also ensures that system withstands major contingencies. PUC has an advantage of giving optimal solution in less time as RUC utilizes extra algorithm to analyse scenarios. LR method is best suited for PUC method which is supported using case studies in results section. Intermittent nature of wind poses numerous problems in scheduling of generators. This section deals with the mathematical modelling of scheduling of generating units. This paper attempts to consider the Intermittency of the wind and provides the solution for unit scheduling of the thermal generators for 24 h.