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On maximizing profit of wind-battery supported power station based on wind power and energy price forecasting

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HIGHLIGHTS

- A strategy for profit maximization of a wind power plant is presented.
- The proposed algorithm is supported with a battery energy storage system.
- The strategy is primarily based on wind power and market price forecasting.

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ABSTRACT

This paper proposes a framework to develop an optimal power dispatch strategy for grid-connected wind power plants containing a Battery Energy Storage System (BESS). Considering the intermittent nature of wind power and rapidly varying electricity market price, short-term forecasting of these variables is used for efficient energy management. The predicted variability trends in market price assist in earning additional income which subsequently increase the operational profit. Then on the basis of income improvement, optimal capacity of the BESS can be determined. The proposed framework utilizes Dynamic Programming tool which can incorporate the predictions of both wind power and market price simultaneously as inputs in a receding horizon approach. The proposed strategy is validated using real electricity market price and wind power data in different scenarios of BESS power and capacity. The obtained results depict the effectiveness of the strategy to help power system operators in ensuring economically optimal energy dispatch. Moreover, the results can aid power system planners in the selection of optimal BESS capacity for given power ratings in order to maximize their operational profits.

1. Introduction

Electricity generation through wind power has remained a well-researched topic over the last few decades, and is likely to continue in the years to come as progressive nations are setting ambitious targets for building wind energy potential [1]. All around the world, projects involving large scale penetration of wind energy into the grid as well as offshore wind farm establishment are tremendously gaining attention [2]. Researchers and policy makers are foreseeing the prospective contribution of wind energy toward future climate stabilization, reduction of greenhouse gas emissions and minimal dependency on fossil fuels [3]. Hence advancement in wind energy technology can bring significant social and environmental benefits for the society [4].

Despite these merits, wind energy is highly intermittent and uncertain in nature with limited control, making it non-dispatchable and making its higher penetration in a power grid cumbersome [5]. Several studies discuss the impact of wind integration into the grid causing deterioration in power quality, grid stability and generation dispatch [6]. Some of the major issues of identified by researchers in this domain include reserve determination, energy storage system requirements, frequency stability, coordination with electricity market rules and demand response management [7]. The practical research challenges such as wind resource quantification, cost of wind turbine and design of wind turbine array in an optimized fashion are also studied by industry [8]. Power system regulation, control and reliability evaluation also becomes difficult with high wind penetration into the grid [9,10]. The difficulties faced in wind resource assessment and forecasting are also reviewed in literature and their possible remedies

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Nomenclature

List of Abbreviations

AEMO	Australian Energy Market Operator
BESS	Battery Energy Storage System
DP	Dynamic Programming
ES	Energy Storage
MPC	Model Predictive Control
NEM	National Electricity Market
NEMO	National Electricity Market Operator
RRP	Regional Reference Price

Indices

j	discrete time within a prediction horizon; $j \in \{0,...,N\} \in \mathbb{N}$
k	sampling instant (discrete time)
N	prediction horizon

Variables

α_M	maximum allowed BESS capacity in per unit; $\alpha_m < \alpha_M < 1$
α_m	minimum allowed BESS capacity in per unit; $0 < \alpha_m < 1$
$\vec{\omega}(k)$	the symbol "$\rightarrow$" is used to denote a predicted sequence of N future values of $\hat{\omega}(j)$ at the sampling instant k
$\hat{\omega}(j)$	the symbol "^" is used to denote the predicted value of the variable ω at the instant j
c	BESS capacity
g	selling energy
L	stage cost for $j = \{0,...,N-1\}$
m	energy market price
p	wind farm energy
r_c	maximum allowed rate of charge of the BESS
r_d	maximum allowed rate of discharge of the BESS
V	cost function for a prediction horizon N
V_N	terminal cost for $j = N$
x	state of charge of the battery storage energy system (BESS)

have been proposed [11]. Thus, from the perspective of power utilities, cost-effective and reliable operation of power systems embedded with large scale wind power is always seen as a challenge combining technological and economic constraints [12].

There are a number of ways to cater large-scale penetration of wind energy in power systems without drastically diminishing the grid performance [13]. One of the most frequently used techniques in literature for wind farm output power dispatch enhancement is the inclusion of adequately designed and operated Energy Storage System (ESS) into the power system [14]. Several research works exhibit the fact that effective Wind-ESS coordination is able to compensate the expected production aberrations of wind generation [15]. Nowadays, researchers are developing management and control strategies for ESS in renewable energy generation systems and overcoming many problems in power quality, regulation and unit commitment [16]. Similarly, a number of tools have been developed to analyze the economic feasibility for planning and operation of a general wind-storage system [17]. A tutorial on optimization techniques explains how an ESS can be used to devise a policy for effective optimization of power system operation [18].

Today there are several energy storage ESS technologies available in the market (see, e.g., [19] and references therein) including mechanical pumped hydro storage, flywheel storage, hydrogen fuel cells, battery energy storage system and super capacitors, etc. [20]. Among these technologies, the Battery Energy Storage System (BESS) is considered as one of the most promising choice particularly for large power applications due to its wide application and benefits. The ability of flexible charging/discharging of a BESS is analyzed and a strategy for its optimal operation is devised for energy supply networks [21]. It has been shown in literature that appropriately designed BESS based on power forecasting information can be used to enhance the quality of wind power by smoothing the power output of a large wind farm [22]. Similarly, an optimally sized BESS has the ability to improve the management and dispatch strategy of wind energy based renewable energy system [23].

Recent trends in literature suggest that improvement in economic viability of a Wind-BESS power system can be achieved by (1) raw storage material cost reduction; (2) minimization of BESS size; (3) and development of efficient dispatching strategies/procedures [24]. The optimal sizing problem is recently tackled mostly using intelligent optimization techniques. The authors in [25] have used Genetic Algorithm (GA) for optimal ESS sizing while energy management system is devised based on fuzzy expert system. Similarly, a new intelligent method called Bat algorithm is also used to estimate the optimum BESS capacity [26]. A paper on joint BESS sizing and control methodology has presented a framework which can improve the quality of wind power forecasting while reducing the need for load following and regulation [27]. In a similar fashion, intelligent GA and sequential simulations have been utilized for optimal capacity estimation while the results are used in a control strategy based on reliability constraints [28].

Devising an optimal economic dispatch method for wind power plants is a cumbersome task keeping in view the irregular nature of wind speed and hence power, that is why over the past years, researchers have put together appreciable efforts by developing and testing a number control and optimization techniques to address the problem [29]. The authors in [30] have developed a feedback based control strategy for optimal use of BESS by smoothing out the intermittent power. Similarly, an advanced control technique called Model Predictive Control (MPC) is utilized to optimize the BESS operation [31]. A recent article presents multiple control algorithms and sizing methodologies to manage the energy imbalance of wind generation resources, while simultaneously attempting to reduce the ESS size [32]. There is a recent trend of using power and market price forecasting information for dispatch optimization. In this regard, an MPC based optimal control scheme for wind generation and BESS is proposed on the basis of short-term wind power and price forecasting [33]. Similarly, the BESS is made economically more viable by accurately forecasting wind power using Artificial Neural Networks (ANN) and electricity price using Locational Marginal Price (LMP) [34].

The discussed strategies have been able to optimally dispatch the wind power up to a good standard, however, the utilization of forecasting information of both wind power and market pricing in order to extract full optimization outcomes for operation and sizing of renewable power plant is still an area which demands contribution. Also, the algorithms found in literature were formulated and solved as high-dimensional optimization problems that have complex structures and large computational costs. The objective of this paper is to propose an algorithm that incorporates forecasting information simultaneously from wind power and market price to enhance the operation of wind-BESS power plant and to determine the optimal capacity of the BESS needed to maximize the overall income and the operational profit consequently.

The novelty of this work can be highlighted in two main aspects: (1) Formulation of optimization problem in a novel way of incorporating wind power and market price forecasting for a very short time period (5-min dispatch interval) along with the BESS capacity optimization. (2) Setup and solution of the optimization problem into a 1-dimensional system based on Dynamic Programming (DP) theory, so the proposed DP problem has single dimension which makes it much faster from computational viewpoint in comparison with the existing literature.

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