Electrical Power and Energy Systems 33 (2011) 303–314

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A quantitative approach to wind farm diversification and reliability

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ARTICLE INFO

Article history:
Received 19 October 2009
Received in revised form 20 June 2010
Accepted 13 August 2010

keywords:
Wind farm diversification/geographical dispersion
Aggregated wind power output
Correlation
Mean-variance portfolio theory
Convex optimization
Capacity credit

ABSTRACT

This paper proposes a general planning method to minimize the variance of aggregated wind farm power output by optimally distributing a predetermined number of wind turbines over a preselected number of potential wind farming sites. The objective is to facilitate high wind power penetration through the search for steadier overall power output. Another optimization formulation that takes into account the correlations between wind power outputs and load is also presented. Three years of wind data from the recent NREL/3TIER study in the western US provides the statistics for evaluating each site upon their mean power output, variance and correlation with each other so that the best allocations can be determined. The reliability study reported in this paper investigates the impact of wind power output variance reduction on a power system composed of a virtual wind power plant and a load modeled from the 1996 IEEE RTS. Some traditional reliability indices such as the *LOLP* are calculated and it is eventually shown that configurations featuring minimal global power output variances generally prove the most reliable provided the sites are not significantly correlated with the modeled load. Consequently, the choice of uncorrelated/negatively correlated sites is favored.

1. Introduction

The basic goal of wind energy exploitation lies in the economical, sustainable and environmentally-friendly replacement of conventional energy sources such as fossil fuels or nuclear. However, such ambitions assume large scale deployments of wind turbines in order to significantly impact national economies. Many developed countries are already engaged in policies privileging high wind power penetration, setting objectives to be achieved in the decades to come [1–4].

Due to the intermittent nature of the wind itself and the lack of efficient and economic way of storing energy, the main challenge lies in ensuring power system reliability standards at reasonable costs. One goal may then consist in exploiting maximum of wind energy while minimizing the expenditures associated with the compensation of wind power swings by conventional fast ramping generators. A direct approach would consist in finding an efficient way of smoothing out the overall wind power output in order to reduce its variability and make it more predictable. To some extent, this can be made possible by spreading wind farms across diverse geographical areas and aggregating their power outputs, as suggested by some integration studies published in the literature [1–8]. As a matter of fact, the smoothing effect resulting from wind farm deployment across diverse geographical regions is shown to be slight when considering relatively small system areas such as Belgium [9], but prove more compelling in large scale systems as reported by many European studies [1–3,6,7]. This basically illustrates that wind farms far from each other are unlikely to experience wind shortages at the exact same time; in effect, this translates into wind power outputs that are often uncorrelated with each other, meaning that the aggregated wind power output of wind farms spread across long distances is likely to stay within fairly tight limits. Such beneficial effects may effectively enhance wind capacity credit [1,2,4,5,7] and – from an operational point of view – wind power predictability [6]. As such, they might be carefully sought for when planning the construction of a portfolio of wind power. To this end, the exhaustive exploration of various wind power allocations over potential sites remains possible, as exemplified by Archer and Jacobson [10] in their study of 19 midwestern sites, or by Caralis et al. [4] in their case study approach, but such a process is clearly subject to combinatorial explosion and may not be practical for studies considering a large number of sites. Milligan [5] proposes an algorithm based on production costing/reliability methods to find the most reliable allocation of wind power over various wind farms, although such an approach is limited in its range to applications where load and wind patterns can effectively be modeled by independent random variables. Alternatively, some approaches suggest the use of wind patterns positively correlated with the load so as to more conveniently balance out electrical production and consumption. NYSERDA studies [11] report offshore wind farm effective capacities as high as 40% during peak load. Such a result comes close to the energy capacity

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doi:10.1016/j.ijepes.2010.08.027