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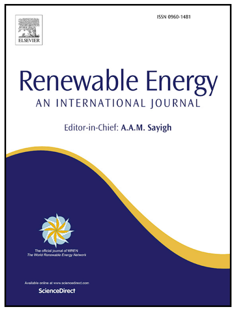

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Numerical Definitions of Wind Power Output Fluctuations for Power System Operations

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Abstract

Because of unpredictable fluctuations in wind power output caused by sudden changes in weather conditions, operations that balance supply and demand in power systems will gradually become more difficult with the massive deployment of wind power generation. Therefore, it is necessary to quantitatively evaluate wind power output fluctuations in a way that corresponds to frequency controls in power system operations. In this study, we analyzed data for the fluctuations of actual wind power output at 20 wind farms, as designated by three basic definitions: the changes in time-averaged values, the maximum power-fluctuation range within a time window, and the deviations from a centered moving average value. The results indicated relevant differences between the definitions and demonstrated the importance of percentile analysis. We proposed a novel quantitative definition of the output fluctuations associated with the frequency controls of power systems: primary turbine-governor control, secondary load-frequency control, and tertiary economic load-dispatch control. Using these definitions to quantify fluctuations demonstrates how each smoothing technique can contribute to reducing the reserve capacity necessary for frequency control in the power system operations. Our proposed definitions for dividing the frequency ranges of the fluctuations were confirmed as a convenient and practical method for quantitatively evaluating the fluctuations and determining the reserve capacity required for stable power system operations.

Keywords: wind power, fluctuation, smoothing effect, power system operation, load frequency control, supply-demand analysis

1. Introduction

Wind power (WP) generation is one of the most widely integrated renewable energy technologies in power systems. With increasing WP penetration of the power market, operations that balance supply and demand in power systems will gradually become more difficult because of the unpredictable fluctuations in WP output caused by sudden changes in weather conditions. Output fluctuations cause not only local voltage problems, such as static voltage fluctuations, instantaneous voltage drops, and voltage flickers, but also whole system problems related to balancing operations [1, 2, 3]. These problems have a negative impact on the further development of renewable energy. In order to mitigate this negative influence, it is absolutely imperative to introduce technologies for reducing output fluctuations.

First of all, quantitative evaluation of output fluctuations is necessary for the introduction and implementation of these technologies. Some studies have analyzed impacts of fluctuations on the power system [4, 5, 6, 7]. To evaluate future total WP output fluctuations in a power system, we must quantitatively understand geographical smoothing effects.

If no definite correlation exists between any two output fluctuations of geographically dispersed wind turbines or wind farms, the synthesized fluctuation is expected to decrease because positive and negative changes in outputs cancel each other. Therefore, the number of wind turbines or wind farms and their geographical distribution are important factors in smoothing effects. Many analyses of geographical smoothing effects have been conducted, as has been reported in many papers. In some studies, the smoothing effects due to the aggregation of multiple wind turbines in a

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