Modeling and forecasting of wind power generation - Regime-switching approaches

The present thesis addresses a number of challenges emerging from the increasing penetration of renewable energy sources into power systems. Focus is placed on wind energy and large-scale offshore wind farms. Indeed, offshore wind power variability is becoming a serious obstacle to the integration of more renewable energy into power systems since these systems are subjected to maintain a strict balance between electricity consumption and production, at any time. For this purpose, wind power forecasts offer an essential support to power system operators. In particular, there is a growing demand for improved forecasts over very short lead times, from a few minutes up to a few hours, because these forecasts, when generated with traditional approaches, are characterized by large uncertainty. In this thesis, this issue is considered from a statistical perspective, with time series models. The primary case study is the Horns Rev wind farm located in the North Sea. Regime-switching aspects of offshore wind power fluctuations are investigated. Several formulations of Markov-Switching models are proposed in order to better characterize the stochastic behavior of the underlying process and improve its predictability. These models assume the existence of a hidden or unobservable regime sequence. Estimation methods are presented in both Bayesian and Frequentist frameworks. Markov-Switching models enable to highlight structural breaks in the dynamics of offshore wind power generation, with alternating periods of high and low variability. They also yield substantial gains in probabilistic forecast accuracy for lead times of a few minutes. However, these models only integrate historical and local measurements of wind power and thus have a limited ability for notifying regime changes for larger lead times. For that purpose, there is a long tradition in using meteorological forecasts of wind speed and direction that are converted into wind power forecasts. Nevertheless, meteorological forecasts are not informative on the intra-hour wind variability and thus cannot be used in the present context focusing on temporal resolutions of a few minutes. Instead, this thesis investigates the use of weather radar observations for monitoring weather conditions in the vicinity of offshore wind farms, with the ambition of establishing a link between the passage of precipitation systems and high wind variability. The underlying motivation of this approach is twofold. First, it aims at providing a meteorological interpretation of the hidden regimes as estimated by regime-switching models. Second, it aims at determining an observed sequence of regimes based on the information extracted from the observations supplied weather radar observations. This approach, combining both meteorological and statistical expertise, opens up new possibilities for designing prediction systems in wind energy.

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