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Diffusion Models for Multivariate Probabilistic Net Load Forecasting in Transmission Grid Congestion Management

Short-term congestion risk assessment in transmission grids is still largely based on deterministic load flow computations from point forecasts. We investigate multivariate probabilistic net load forecasting across substations as a way to better quantify the probability of congestion events, which arise from correlated forecast errors across substations. This is particularly challenging with growing renewable penetration, which induces high-dimensional joint distributions with complex, often strongly non-Gaussian behaviour and strong spatial dependence. In this context, we develop and assess a denoising diffusion probabilistic model designed to generate joint predictive distributions with calibrated univariate behaviour and realistic spatial dependence across substations.

Our study focuses on three-hour-ahead forecasting at 115 substations on the French extra-high-voltage grid. We compare this approach with alternative strategies for constructing multivariate predictive distributions, combining different marginal models —including empirical residual-based methods and quantile regression —with different dependence structures such as Gaussian and empirical copulas. The comparison is intended to clarify whether diffusion-based generative modelling yields practical benefits over simpler statistical approaches in this setting.

Performance is evaluated using multivariate proper scoring rules together with operational metrics relevant for congestion risk. We also discuss permutation-invariant model designs to handle unseen substations and hierarchical extensions to scale probabilistic forecasting to the roughly 5,000 substations of the French grid.

Special/ Invited session

Classification

Mainly application

Keywords

diffusion models, power systems, probabilistic forecasting

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