Accounting for spatio-temporal effects when forecasting wind power generation

Julija Tastu*, Pierre Pinson, and Henrik Madsen

DTU Informatics, Technical University of Denmark

* Corresponding author: J. Tastu, email: jvl@imm.dtu.dk

Motivation

Nowadays when the fossil fuel prices are expected to keep raising, the climate change is a globally admitted fact and nuclear energy is causing serious debates in relation to its safety, wind energy is being considered more and more as a part of the global solution. Currently wind energy meets 5.5% of the EU's electricity consumption. Denmark is the leader with over 25 % of national electricity demand coming from wind energy. According to a new Danish energy agreement this number should raise up to 50 % by 2020.

Such large scale penetration of wind energy puts an increased emphasis not only on the benefits offered by wind power (renewable green energy at a very low marginal cost), but it also lights up the associated challenges. The main one comes with the intermittent nature of wind. It is not only impossible to control weather conditions, it is also difficult to know in advance how strong wind will be. Uncertainty in the meteorological conditions translates to uncertainty in wind power production. This causes difficulties in operation and management of the power systems as well as in trading of wind energy.

What can we do

For the optimal integration of wind energy into power systems high quality wind power forecasts are required. It is preferable that the forecasts provide the user not only with the expected values of the future power generation, but also with the uncertainty associated with the prediction. This calls for probabilistic rather than point forecasting.

As for now, operational state-of-the-art wind power prediction systems generate forecasts for each site of interest individually, without properly accounting for the information coming from the neighbouring territories. However, due to the inertia of meteorological systems, there exists a spatio-temporal dependence between the sites - the errors of wind power forecasts propagate in space and time under the influence of meteorological conditions. Our work focuses on capturing this dependency and correcting wind power forecasts correspondingly.

How do we do it

We put ourselves in probabilistic forecasting framework. All the considered estimation techniques are made in adaptive recursive manner both to ease computational load and to account for long term variations in meteorological systems.

Two different ways of building predictive densities of the future power generation are considered: a parametric and a non-parametric one.

The parametric approach is based on the assumption that wind power variable follows censored Gaussian distribution. Censoring is needed in order to respect natural generation bounds of 0 and nominal generation capacity. Censored Gaussian distribution is described by two parameters: location and scale. The location parameter is closely related to the conditional expectation or, in other words, to the first order moment of the wind power generation. The scale parameter relates to the variance and is estimated by modelling squared deviations from the conditional expectation. Thus, the two parameters correspond to the first two order moments of the wind power variable.

The goal is to consider spatio-temporal dynamics when building the predictive densities, and the problem boils down to finding ways to account for it when estimating the first two moments. An interesting question is whether spatio-temporal effects influence both the mean and the variance or only one of them. The parameters are described as smooth functions of meteorological conditions (represented by the forecasted wind direction), spatial information (given by the forecast errors observed at the neighbouring territories) and the expected generation level.

For modelling the conditional expectation (the scale parameter of the predictive distribution) we use Conditional Parametric AutoRegressive models with eXogenous input (CP-ARX). These models comprise a class of models with a linear structure, but for which the coefficients are replaced by smooth functions of other variables. In our case to capture the influence of meteorological conditions the smooth functions are functions of forecasted wind direction. Spatial information enters the model as the exogenous input.

For describing the variance Conditional Parametric ARCH model with eXogenous input (CP-ARCHX) is used. The coefficients of the model are described as smooth functions of power generation level. This takes into account that larger fluctuations of wind power come in the periods when the generation level is not close to the bounds (due to the sigmoid shaped relation between wind speed and the corresponding generated power).

The non-parametric approach for estimating the predictive densities does not assume any specific, known distribution for the data. Instead, it suggests estimating quantiles of the data directly from the observations. In this work time-adaptive quantile regression is used. The model uses conditional expectation of the wind power as input. Spatial information can enter the model as an additional explanatory regression variable. In other words, the first order moment of the predictive density enters the model as input. Therefore it needs to be estimated separately (using CP-ARX models, for instance). Higher order moments are give through the quantiles found by using regression techniques.

Discussion and results The models considered in the study can be viewed as general ones. They can be used for correcting forecasts issued for a single wind farm or for a larger territory aggregating a set of wind farms. We focus on probabilistic forecasts. Traditional point predictions giving the power expectation, only, can be easily extracted. We have validated our modelling approaches on two different test cases.

Firstly, we looked at the 15 groups of wind farms spread throughout the territory of Western Denmark (see Figure 1). The focus is given to the spatial

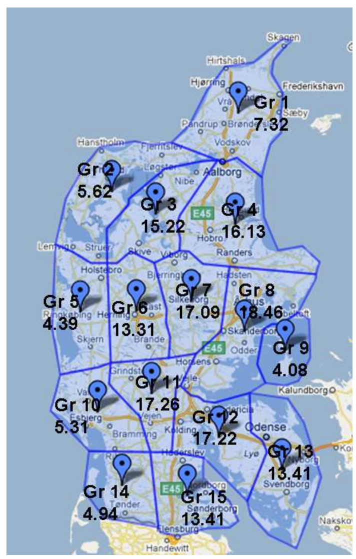

Fig. 1. Predictive performance of the CP-VAR model in terms of a percentage reduction in the RMSE (Δ RMSE) of the forecast errors.(produced using http://maps.google.dk/)

correction of the first order moment. The accuracy of the spatially corrected forecasts is compared to that of original forecasts given by the state-of-the-art prediction tool based on the RMSE criterion. The reduction in the RMSE (denoted as Δ RMSE) is given as a percentage decrease in the RMSE in comparison to the RMSE of the original forecast for each group. The results are presented in Figure 1. One can note that larger improvements (17-18%) correspond to the eastern part of the region. This is in line with the fact that in Denmark the prevailing wind direction is westerly. Due to that easterly located groups are usually situated "down-wind" and can benefit well from the information extracted from the "up-wind" territories. This indicates that the spatio-temporal dynamics are adequately accounted for by the model. It results in improving the accuracy of the conditional expectation of the future wind power generation.

The second case study targeted Nysted Offshore wind farm. Neighbouring smaller farms were used as explanatory variables for capturing spatio-temporal effects. The motivation to target Nysted Offshore was based on the fact that it is the largest wind farm in DK2, neighbouring a lot of "upwind" situated sites. Multistep-ahead (from 15 min to 8 hours ahead) forecasts were considered. The results showed that when focusing on the first order moment only, the maximum improvement in terms of the RMSE was observed for the prediction horizons of 2-4 hours and was reaching 9%. This is lower than was observed for the grouped data. This could be explained by the higher influence of local variations when considering a single farm.

Evaluation of the full predictive densities showed that the quality of the probabilistic forecasts improves when the spatial effects are taken into account. This was valid for all the considered prediction horizons. It has been also demonstrated that it is sufficient to account for the spatio-temporal dynamics when modelling the first order moment. Spatial correction of the higher order moments was shown not to ameliorate the quality of the predictive densities any further.

The performance of the parametric and the non-parametric probabilistic densities has also been compared. It is shown that both approaches perform similarly (in terms of the average accuracy given by the Continuous Ranked Probability Score (CRPS)) in the short prediction horizons (up to 5-6 hours ahead). In the longer horizons the difference in performance becomes more significant with the non-parametric models taking the leading position. The best-performing model suggested in the study is based on the time-adaptive quantile regression using the spatially corrected point predictions (CP-ARX) as input. It consistently outperforms the benchmark approach in all the considered horizons. The relative improvements in overall quality (given by the CRPS criterion) are ranging from 1.5% to 4.7% depending on the prediction horizon.