

論文 / 著書情報  
Article / Book Information

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## 論文要旨

THESIS SUMMARY

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### 要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words )

To reverse and mitigate the effects of climate change and limit global warming below two degrees it is necessary to transition to renewable energy generation. Four technologies lead this transition: hydropower, wind power, photovoltaic solar and biofuels, and several countries are already able to generate more than 20% their energy needs from renewable energy sources. However the case of Japan is different, in the Asian country the transition has been slow when compared to other nations. This is despite their considerable potential for renewable energy generation, including wind power.

Resource availability is not sufficient. To guarantee grid connectivity and reliability when there are variable renewable resources (such as solar and wind) it is necessary to obtain power output estimations. This implies the need for accurate weather forecasting. In the case of Japan, obtaining wind forecasts is complicated by the complex mountainous terrain of the country. A literature review revealed that methods for improving weather forecasts targeted at power estimation in zones with rugged terrain is virtually non-existing.

The main objective of this thesis was therefore to develop wind speed predictions models focused at obtaining wind power estimations. Machine learning approaches were chosen due to their versatility and the availability of both observed and predicted data. This data used in this thesis comes from two wind farms located in a zones with mountainous and steep terrain, therefore providing the model information about complex and turbulent wind profiles. Out of several machine learning methods available, neural networks were chosen for their adaptability and scalability. The developed models included long short-term memory networks, autoencoders and generative models. Three approaches were explored: a pure data-based wind speed prediction model, a deterministic numerical forecast prediction (NWP) forecast correction model and a probabilistic NWP forecast correction model.

Wind speed and power data was obtained from a wind farm located Awaji Island (Hyogo Prefecture), and another wind farm located in the Houhoku region (Yamaguchi Prefecture). These are two regions with rugged terrain and complex landforms that result in highly fluctuating wind speed patterns. Measured wind speed data was obtained for each turbine by using anemometers positioned on top of the nacelle after the rotating blades. In the case of the Awaji Island wind farm, numerical weather predictions (NWP) were obtained by using the NWP model with initial and boundary conditions from the Global Forecast System (GFS) and a 4-domain grid implementation. With respect of the power estimation model, a non-linear power-curve model was chosen to fit wind and power data.

The first model approach consisted of a pure data-based model for wind speed prediction. Past wind speed observations were treated as amplitude-modulated-frequency-modulated (AM-FM) signals in order to apply variational mode decomposition (VMD). The resulting sub-signals were forecasted ahead in time by using long short-term memory (LSTM) networks to obtain 24-hour day ahead forecasts. Results showed that for the present dataset and the employed VMD implementation, decomposing wind speed time series did not result in pure harmonics that would have made prediction easier. More importantly, the reconstructed predictions showed satisfactory results for the immediate prediction times, but their performance decrease drastically with time. Both root mean square error (RMSE) and the mean absolute error (MAE) increased sharply after a few time steps, from 1.36 m/s to 3.02 m/s in the case of the RMSE, and from 1.02 to 2.37 m/s in the case of the MAE. The correlation coefficient (CC) showed also a drastic decline, from 0.87 to practically zero. It was concluded that pure data-based models are inadequate for wind speed forecasting and that the inclusion of NWP models is necessary.

The second introduced approach was a deterministic model for machine learning-based correction of wind speed forecasts. Development was inspired by denoising autoencoders, which are a special neural network architecture designed to eliminate noise from data. Two networks were introduced: a single-variable input network (NN-S, for wind speed) and a multi-variable input network (NN-SDPT for wind speed, wind direction, pressure and temperature). Results showed that both models were able to reduce the bias in the NWP results for all sites and all forecast lead times. Also, both models were superior when compared to the Model Output Statistics (MOS) baseline methods. On average, the NN-S and NN-SDPT networks, respectively, reduced the root mean square error by 11.55% and 16.52% and the mean absolute error by 10.74% and 16.32%, and improved the correlation coefficient by 8.21% and 13.20%. As a matter of fact, the multi-variable network was superior in most metrics when compared to the single-variable network. Also, the multivariable network was able to recover some of the variance in the forecast, which was lost in the single-variable network. It was concluded that (a) hybrid NWP and data-based methods are much more adequate for wind speed prediction (compared to the pure data-based method), and that (b) there is hidden, valuable information about the state of the atmosphere in other variables such as wind direction, pressure, and temperature forecasts, and including these forecasts enhances the wind speed correction process.

The third and final introduced approach is a probabilistic model for the correction of wind speed forecasts. This model was based on the conditional variational autoencoder (CVAE) generative approach to obtain enhanced ensemble forecasts from deterministic NWP predictions. The input of the model consisted of a multivariable forecast (similar to the NN-SDPT network), but also contained spatio-temporal features. Ensemble forecasts were obtained by sampling repeatedly from the generation network for a given input. The model was evaluated from both a deterministic perspective (by using the mean of the ensemble) and from a probabilistic perspective (by using the ensemble.) Results showed that the CVAE was able to provide ensembles with superior properties when compared the MOS and analog ensemble baseline methods. From a deterministic point of view, the CVAE was able to, on average, reduce the root mean square error by 16.7% and the mean absolute error by 17.1%, and improve the correlation coefficient by 13.9%. From a probabilistic point of view, the CVAE showed smaller RMSE and MAE for all sites and lead times when compared to MOS. From a probabilistic point of view, the CVAE ensemble showed better probabilistic skills and slightly improved rank histograms and dispersion diagrams when compared to the analog ensemble. A power curve model was constructed from past speed and power data and used to obtain power estimations with the CVAE results. It was seen that wind speed predictions with reduced error result directly in power estimations with reduced error as well. As an overall conclusion, it was proposed that probabilistic correction methods offer the best alternative for wind speed and power estimation.

This work finalizes with an overall review and comments, and possible directions for further research.

備考：論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

Note：Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1 copy of 800 Words (English).

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