The Application of On-line Numerical Weather Predictions in Wind Power Forecasting in Penghu

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Abstract

The first application of on-line numerical weather predictions (NWP) from Central Weather Bureau in wind power forecasting in Taiwan is reported. A wind power forecasting system with a forecast length up to 48 hours for minimizing the impact and optimizing the produced electricity in the grid in Penghu, one of the areas with the richest resources of wind energy worldwide, is developed by Taiwan Power Company. Based on fuzzy-neural networks, the system uses the on-line NWP data and supervisory control and data acquisition (SCADA) measurements of wind turbines as inputs to predict the power production of Jhongtun and Hushi wind farms. The root mean square error of the forecast for 6 hours ahead and 24 hours ahead regarding Hushi Wind Turbine #1 over a period between 2014-01-01 and 2014-06-30 are 19% and 22%, respectively. The results indicate the on-line NWP applied in wind power forecasting in Penghu is promising.

Key word: Wind power forecasting, numerical weather prediction, fuzzy-neural networks

1. Introduction

Penghu has been chosen as a pilot case to illustrate the strategies to establish a low-carbon society in Taiwan. To reduce 50% of total carbon emission in Penghu, the use of renewable energies should be maximized in the area. Among the various renewable energy candidates, wind power is the most important as Penghu is one of the areas with the richest resources of wind energy worldwide. However, the penetration of wind power normally poses challenges in grid management and generation scheduling due to the inherent intermittency and variability of wind energy. The challenge in Penghu, where two wind farms, Jhongtun and Hushi, are located, is even more severe nowadays. This is because, compared to that in Taiwan, the power system in Penghu is more vulnerable to the impact of wind power penetration as the system is isolated and wind power may account for over 30% of the total electricity generation during winter. An advanced wind power forecasting system for assisting power system operations, therefore, is becoming essential.

Advanced wind power forecasting systems employed in the world are mainly based on statistical, physical, or/and the combination of the two approaches [1]. A very comprehensive literature overview about the state-of-the-art in short-term prediction of wind power is provided by ANEMOS.plus project [2]. In Taiwan, most of the researchers focused on the development of novel forecast models by using historical data [3] but just limited in simulation or off-line forecasting. From a utility's point of view, a wind power forecasting system with a forecast length up to 48 hours for unit commitment, economic dispatch, and dynamic security assessment would be required. However, to realize a system with such a forecast length, on-line numerical weather predictions become indispensable. Supported kindly by Central Weather Bureau (CWB), on-line numerical weather prediction (NWP) for Penghu and Kinmen is provided to Taiwan Power Company (TPC) for developing such an advanced wind power forecasting system to meet the aforementioned requirement. Here the interest is confined to the two wind farms, Jhongtun and Hushi, in Penghu. This paper first focuses on the development of the forecasting system, including the validation of NWP and the design of the system. Then, the on-line operation and verification will be discussed, followed by future work and conclusions.

2. System development

2.1 Validation of NWP

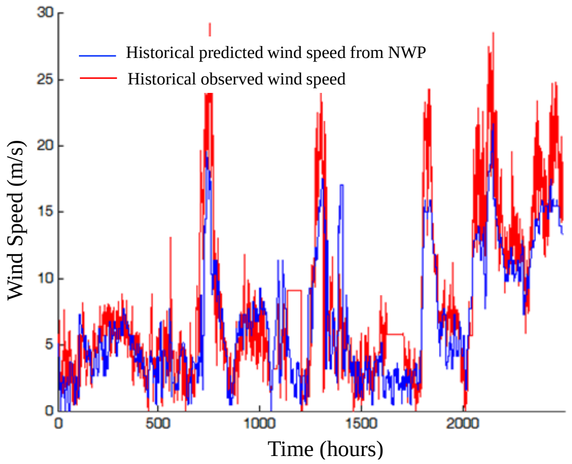

Figure 1 Comparison of the two time series of data of the observed wind speed at the hub of Wind Turbine #1 at Jhongtun Wind Farm and predicted wind speed from NWP at the considered site in the period between 2012-7-1~ 2012-10-17.

As this seems the first application of NWP in wind power forecasting in Taiwan, the NWP data is validated by exploring the correlation between the two time series of data of the observed wind speed at the hub of wind turbine and wind speed predicted at the considered site at the beginning of the project. Figure 1 compares the two time series of data the observed wind speed at the hub of Wind Turbine #1 at Jhongtun Wind Farm and predicted wind speed at the wind farm in the period between 2012-7-1~ 2012-10-17. As shown in the figure, the trends of both time series of data are apparently consistent yet with different magnitudes, attributed to the different elevations. Based on the validation, it is expected that the appropriate use of the NWP data with an intelligent approach, such as fuzzy neural networks (FNNs), would result to a satisfactory wind power forecasting system. The details of the system design are described in the following sub-section.

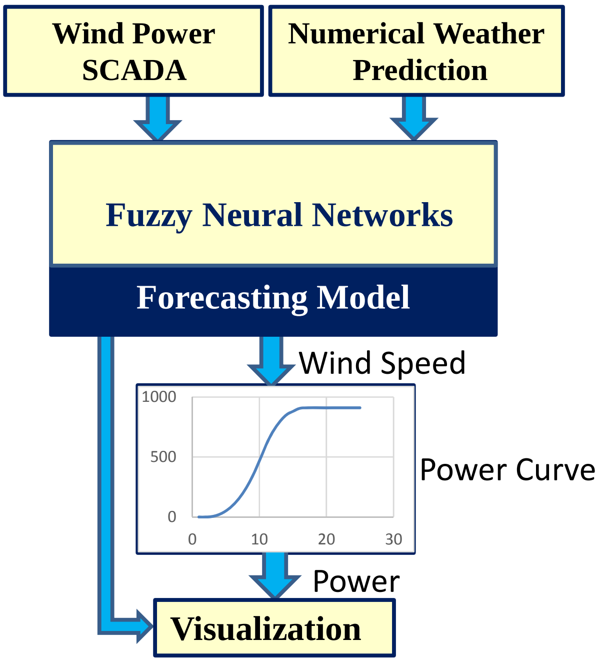

Figure 2 Illustration of the configuration of the developed wind power forecasting system.

2.2 Design of the system

Figure 2 illustrates the configuration of the developed wind power forecasting system. As illustrated, the system is composed of five components, including Wind Power supervisory control and data acquisition (SCADA) component, NWP component, Forecasting Model component, Power Conversion component, and Visualization component. Among the components, the Forecasting Model component is the most important and integrates all the other components. The Forecasting

Model is based on FNNs over MATLAB platform. FNNs is suitable for wind power prediction, owing to the combination of the linguistic reference ability based on expert knowledge of fuzzy logic systems and the learning ability of artificial neural networks. More detailed description about FNNs can be found in [4-6] or elsewhere. Providing various tool boxes, such as Fuzzy as well as Neural Network tool boxes, which are widely used globally and readily available for our work, MATLAB is thus chosen as the platform.

Another component is Wind Power SCADA component, which is an existing OSIsoft Plant Information System, collecting real-time data of all wind farms owned by TPC. The wind speed at the considered site and hub height of wind turbine is periodically read by a client program written in MATLAB from the SCADA component and fed as input of the FNNs component. In the meantime, the meteorological data from NWP component is also fed as input of the FNNs component. Receiving the meteorological data regularly sent by CWB, the NWP component actually is a FTP server. A new prediction at 10 m above ground level is brought out every 6 hours by CWB, similar to many large weather centers in the world. The prediction length is 7 days with a time resolution of 3 hours. Table 1 summarizes the features of the meteorological data form NWP.

Table 1. Summary of the features of the meteorological data form NWP

Height	Prediction Length	Time Resolution	Update Frequency
10 m a.g.l.	7 days	3 hours	4 predictions/ day

Working as the kernel of the system, the FNNs component subsequently calculates the hourly 1-48 hours ahead wind speed at the considered site and hub height of wind turbine. 6 input nodes are fed by 3 consecutive hourly wind speed data from Wind Power SCADA as well as 3 consecutive hourly future wind speed data from NWP. The predicted wind speed at next hour is iteratively calculated by the FNNs component. To obtain the forecasted power generated by a wind turbine, Power Conversion component then converts the wind speed into power with a manufacturer power curve. The predicted wind speed and power, finally, are presented via the Visualization component.

3. Operation and verification

So far there are three wind farms, Jhongtun, Hushi, and Kinsha covered by the embryo of reported wind power forecasting system, which has been implemented since October 2013. Here only Jhongtun (600kW ×8) and Hushi (900kW ×6) Wind Farms are of interest as they are located in Penghu. During operation, the FNNs component receives on-line SCADA measurements and NWP as inputs to forecast the power production of wind farms 1-48 hours ahead. A historical query of a good 48 hour-ahead wind speed forecast of Hushi Wind Turbine #1 is shown in Figure 3. The historical data of 1 hour-ahead forecasted wind speed and observed wind speed are also shown in the figure for reference. As shown, the 1-48 ahead forecast of wind speed meets the overall trend of the observed wind speed quite well although the former is quite smooth while the latter fluctuates. Figure 4 shows a historical query of a good 48 hour-ahead wind power forecast corresponding to Figure 3. Similarly, also shown in the figure is the historical data of 1 hour-ahead forecasted power and measured power. Again, the forecasted result is satisfactory. We notice that the on-line measured wind speeds from SCADA dominates the shorter term prediction as our forecast model contains autoregressive parts dependent on on-line data. On the other hand, the predicted wind speeds from NWP dominate the longer term prediction.

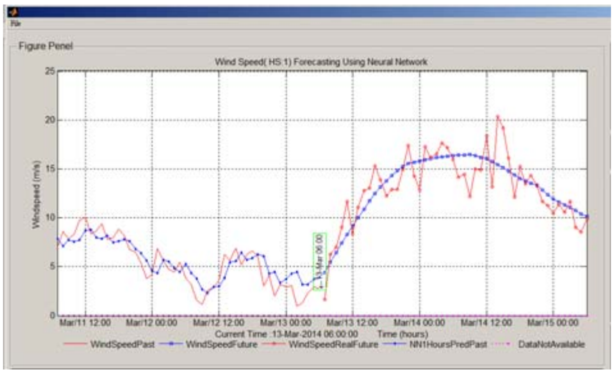

Figure 3 A historical query of a good 48 hour-ahead wind speed forecast of Hushi Wind Turbine#1.

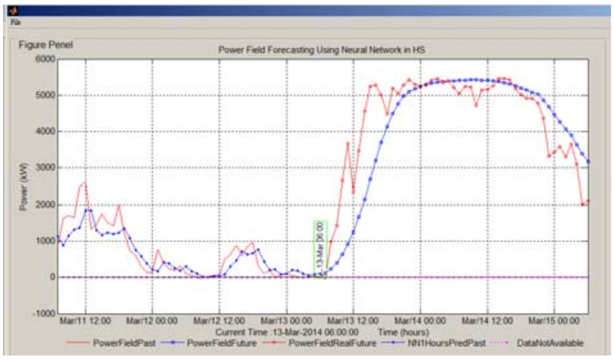

Figure 4 A historical query of a good 48 hour-ahead wind power forecast of Hushi Wind Turbine#1.

However, our model (TPC-FNNs), similar to the models employed in other areas globally, can be good at one particular error, and bad at another. Figure 5 shows an example of a poor on-line 48 hour-ahead wind speed forecasting of Jhongtun Wind Turbine #1. The trend of the forecasted wind speed is not well consistent with that of the observed one during the time beyond March 06 12:00 while under forecast appears over the entire 48 hours of forecast length. The inconsistence and under forecast mainly result from the NWP data, which deviates from the observed data, as highlighted in Figure 6. In contrast, a case of over forecast of wind speed of Jhongtun Wind Turbine #1 is shown in Figure 7. The over forecast is attributed to the over prediction of NWP data shown in Figure 8. The discussion of the two cases above indicate that the accuracy of NWP may significantly influence the forecasting, in agreement with the fact that most of the errors on wind power forecasting come from the NWP model [3]. It is expected that the performance of our forecasting system would be further improved if the accuracy of the NWP is higher.

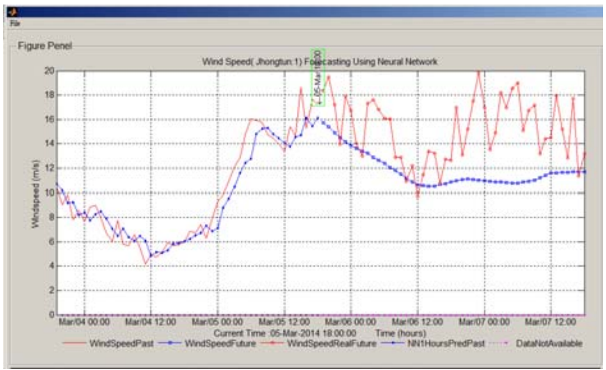

Figure 5 A historical query of a poor 48 hour-ahead wind speed forecast of Jhongtun Wind Turbine#1.

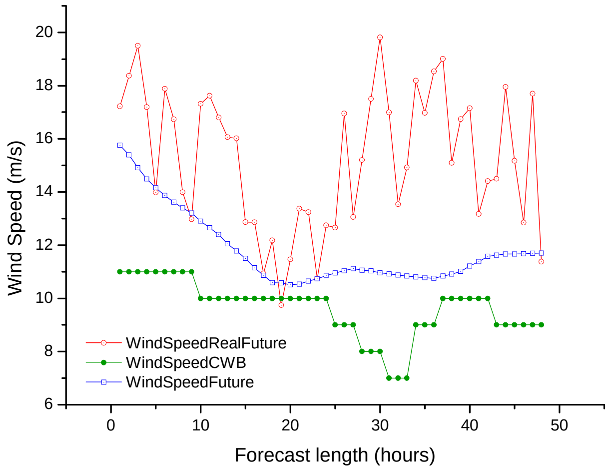

Figure 6 The highlighted inconsistence in trend and under forecast mainly result from the NWP data, which deviates from the observed data extracted from Figure 5.

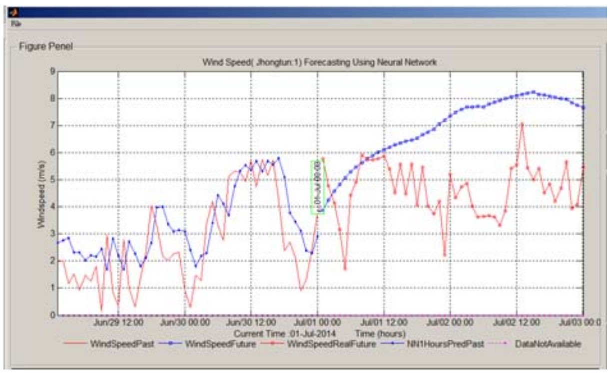

Figure 7 Another historical query of a poor 48 hour-ahead wind speed forecast of Jhongtun Wind Turbine#1.

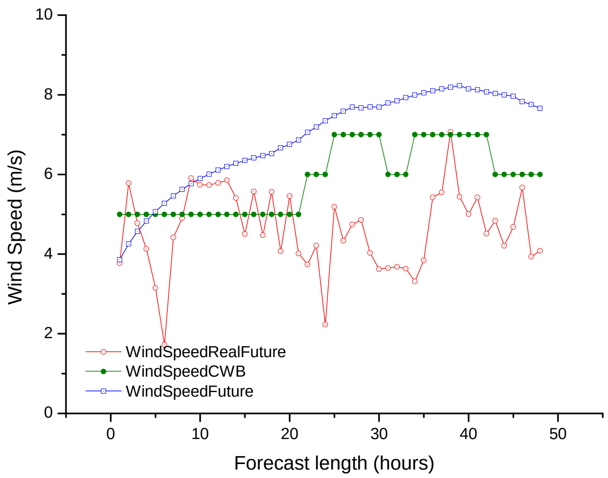

Figure 8 The highlighted inconsistence in trend and over forecast mainly result from the NWP data, which deviates from the observed data extracted from Figure 7.

According to the discussion above, clearly, our model (TPC-FNNs) can be good at one particular error, and bad at another, similar to the models employed in other areas worldwide. Normalized root mean square error (RMSE), as defined in [3] is used as the error measure to verify the performance of TPC-FNNs. The root mean square error of the forecast for 6 hours ahead and 24 hours ahead regarding Hushi Wind Turbine #1 over a period between 2014-01-01 and 2014-06-30 is examined. The values are compared with the primary forecast models used in North American and are just slightly higher than those of WPPT [7]. It should be noticed that this case study is only for the wind speed and wind power forecasting of Wind Turbine #1 at Hushi wind farm and the forecast accuracy would be further improved by aggregating all wind turbines over a wind farm. This is due to statistical effects, which may cancel out weakly correlated forecast errors [2].

4. Future work

4.1 Forecasting quality improvements

The improvements in forecasting quality here imply the reduction of level errors and phase errors, which may be achieved in a number of aspects. Firstly, measured power data will be used as an additional input of the forecasting system. It was reported that the use of actual power data may lead to the decrease of the residual errors [2]. Moreover, to accommodate different type of terrains, such as flat, hilly, and complex terrains, the consideration of wind direction and terrain seems inevitable. In addition, the use of the combination of different NWP models instead of a single NWP model would be also helpful. According to literature [8], using the combination of different NWP models instead of a single NWP model may improve the NWP input, thus leading to a significant improvement in forecasting accuracy. However, the obtainment of different NWP models would highly rely on external support.

4.2 Expansion of the system scale

In current stage, the reported forecasting system only covers three wind farms, Jhongtun, Hushi, and Kinsha. The former two are located in Penghu while the latter located in Kinmen. For the functions of unit commitment, economic dispatch, and dynamic security assessment of the power system, the upscaling of the forecasting system into the total TPC service area is necessary. However, two issues will arise owing to the upscaling. The first is how to predict the output of non-TPC wind farms, which account for roughly a half of the total installed capacity of wind power in Taiwan but whose data TPC has no access to. The other is the need of NWP data for more sites. Therefore, further support from CWB or other organization would be indispensable.

5. Conclusions

The first application of on-line NWP from Central Weather Bureau in wind power forecasting in Taiwan is reported. A wind power forecasting system with a forecast length up to 48 hours for minimizing the impact and optimizing the produced electricity in the grid in Penghu, one of the areas with the richest resources of wind power worldwide, is developed by Taiwan Power Company. Two case studies of Jhongtun Wind Turbine #1 indicate that the accuracy of NWP may significantly influence the forecasting. The performance of our forecasting system would be further improved if the accuracy of the NWP is higher. The root mean square error of the forecast for 6 hours ahead and 24 hours ahead regarding Hushi Wind Turbine #1 over a period between 2014-01-01 and 2014-06-30 are 19% and 22%, respectively, just slightly higher than those of WPPT. The results of the on-line NWP applied in wind power forecasting in Penghu indicate the application of is promising.

6. Acknowledgements

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