Short-and Long-Term Wind Farm Power Prediction

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Outline

- Forecasting from weather based and SCADA data
- Basic methods for wind farm power prediction using data from weather forecasting models
- Short-term and long-term prediction
- Conclusions

NAM weather forecasting model

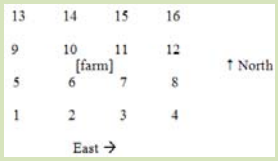
- North American Mesoscale (NAM) model
- A day-ahead forecasting with maximum forecast length of 84 hours
- The spacing between model's grid points is 40 km
- A new 84-hour forecast is issued 4 times daily at 00, 06, 12, and, 18 GMT
- The forecasted value is saved every 3 hours
- Data source for long-term wind farm power prediction

RUC weather forecasting model

- Rapid Update Cycle (RUC) model
- Short-term forecasting model with maximum 12-hour forecast length
- The spacing between model's grid points is 20 km
- Hourly forecasts are issued at 00, 03, 06, 09, 12, 15, 18, and 21 GMT
- Besides the 12-hour forecast, a 9-hour forecast is issued every other hour
- Data source for short-term wind farm power prediction

General characterization of weather forecasting data

- 16 model data points surrounding the wind farm site are extracted for wind power forecasting



The wind farm is located between the model data points: 6, 7, 10, and 11

NAM data description

Parameter	Description	Unit
Spd_10m	Wind speed 10 m above the surface	m/s
Dir_10m	Wind direction 10 m above the surface	deg
Spd_XXmb	Average wind speed in the lowest XX mb of the atmosphere (XX is 30, 60 and 90 respectively)	m/s
Dir_XXmb	Average wind direction in the lower XX mb of the atmosphere (XX is 30, 60 and 90 respectively)	deg
AD_30mb	Average air density in the lowest 30 mb of the atmosphere	kg/m^3
PTdiff_30mb_sfc	Potential temperature difference between the surface and 30 mb above the surface; Measure of atmospheric stability in lower space	K
SHTFL	Sensible heat flux at the surface; Indicator of surface heating or cooling	W/m^2
VEG	Percentage of the surface that is covered by vegetation	%

Each of the 16 points has 12 parameters; 12 * 16 = 192!

Millibar-height conversion

1000 mb ~ 360 feet (110 m)
850 mb ~ 5000 feet (1500 m)
700 mb ~ 10,000 feet (3000 m)
500 mb ~ 18,000 feet (5400 m)
250 mb ~ 34,000 feet (10,200 m)

RUC data description

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Spd_10m	Wind speed 10 m above the surface	m/s
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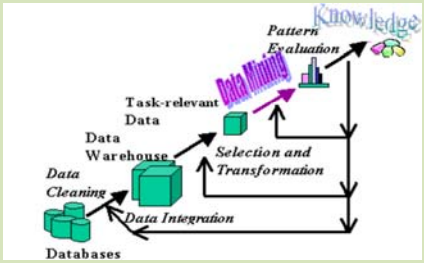
Each of the 16 points has 10 parameters; 16 * 10 = 160!

General characteristics of SCADA data

- Supervisory Control and Data Acquisition (SCADA) system collects wind turbine data
- The wind farm in this research contains 76 wind turbines
- SCADA collects data for more than 120 parameters at each turbine (including wind speed, wind direction, power and so on) and many wind farm level data
- Data is stored at 10-minute intervals (10-minute average data)
- Source for data-driven performance analysis of wind farm

Data mining

- Data mining is a tool for extracting knowledge and solving problems



Parameter selection and transformation

- The four closest model points 6, 7, 10, and 11 are selected as predictors for the wind farm power
- To obtain an accurate prediction model with a data mining approach, the original high-dimension data need to be transformed into low-dimension data vectors
- The original 192-demension NAM data has been reduced to a 8-demension predictor for long-term wind farm power prediction; The original 160-demension NAM data has been reduced to a 6-demension predictor for short-term wind farm power prediction

Measures of prediction accuracy

- AE: Absolute error (%) $AE = \frac{|\hat{y}(t+T) - y(t+T)|}{NRP} \times 100\%$
- Definition: The absolute value of the difference between the predicted and actual power output, and it is expressed as percentage of the installed nameplate rating

- MAE: Mean absolute error (%), average of the absolute error over particular data set
- Std (%): The standard deviation of the AE
- MAE and Std are widely used metrics in industry and research

$$MAE = \frac{\sum_{i=1}^{N} AE(i)}{N} \qquad Std = \sqrt{\frac{\sum_{i=1}^{N} (AE(i) - MAE)}{N-1}}$$

SCADA data predictions

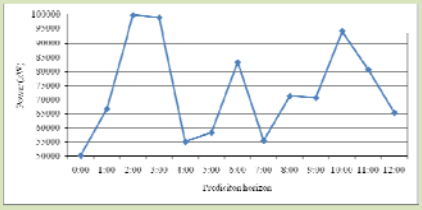
Horizon	MAE	Standard Deviation
10 Minute prediction	2.213	2.501
20 Minute prediction	3.912	4.083
30 Minute prediction	5.143	5.149
40 Minute prediction	6.062	5.917
50 Minute prediction	6.721	6.567
60 Minute prediction	7.384	6.987
70 Minute prediction	8.025	7.514

SCADA data predictions

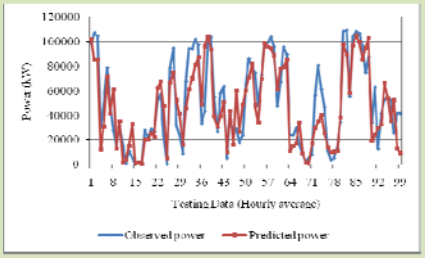
Horizon	MAE	Standard Deviation
1h prediction	5.850997	5.654549
2h prediction	9.336708	8.916529
3h prediction	11.82863	11.23414
4h Prediction	14.99185	13.20335

Short-term power predictions: RUC data

- Output: hourly power, average power over an hour
- Following the RUC forecasting horizon and steps, prediction can be done from 1 hour to 12 hours ahead (T + 1, T + 2,…, T + 12)

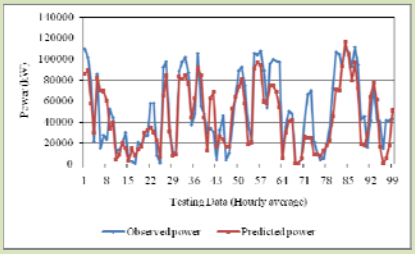


T + 3 power prediction



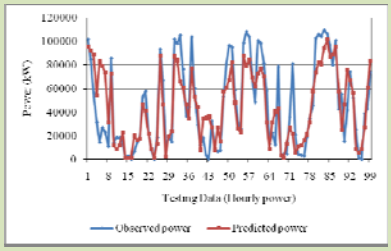
MAE(%): 9.76 Std(%):8.694

T + 6 Power prediction



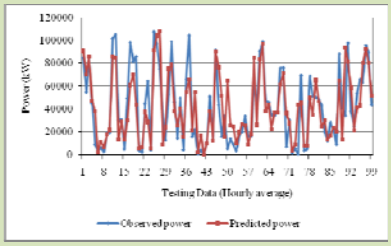
MAE(%): 10.94 Std(%):9.99

T + 8 Power prediction



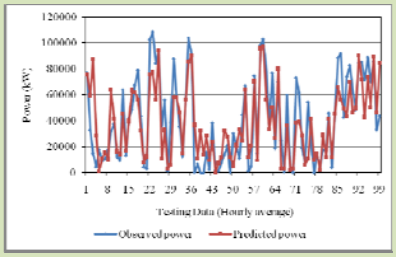
MAE(%): 10.57 Std(%):9.91

T + 10 Power prediction



MAE(%): 11.06 Std(%):10.03

T + 12 Power prediction



MAE(%): 11.49 Std(%):10.53

Statistics of short-term predictions: RUC model data

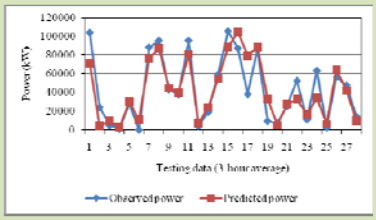
Prediction	MAE (%)	Std (%)	Prediction	MAE (%)	Std (%)
T+1	9.28	8.12	T+7	9.82	9.19
T+2	9.35	8.21	T+8	10.57	9.91
T+3	9.76	8.69	T+9	8.41	8.73
T+4	9.36	8.32	T+10	11.06	10.63
T+5	9.97	8.93	T+11	11.19	9.08
T+6	10.49	9.99	T+12	11.49	10.53

Long-term predictions: NAM model data

- Output: 3-hour power (average power over 3 hours)
- Following the NAM forecasting horizon and steps, prediction can be done from 3 hour to 84 hours ahead (T+3, T+6,…, T+84)

T + 9 power prediction

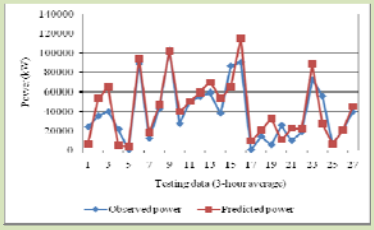
- 3-hour power during T + 6 and T + 9



MAE(%): 9.12 Std(%):8.91

T + 21 power prediction

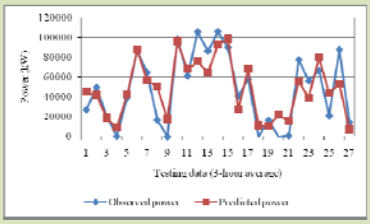
- 3-hour power during T + 18 and T + 21



MAE(%): 9.39 Std(%):7.28

T + 39 power prediction

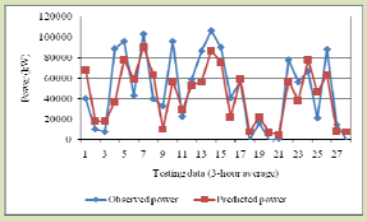
- 3-hour power during T + 36 and T + 39



MAE(%): 11.63 Std(%): 7.79

T+57 power prediction

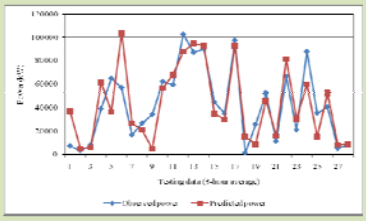
- 3-hour power during T + 54 and T + 57



MAE(%): 13.82 Std(%):9.81

T+75 power prediction

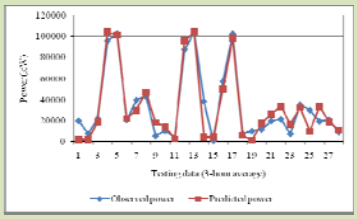
- 3-hour power during T + 72 and T + 75



MAE(%): 10.83 Std(%):9.32

T + 81 power prediction

- 3-hour power during T + 78 and T + 81



MAE(%): 6.37 Std(%):6.19

Statistics of long-term prediction: NAM model data

Prediction	MAE (%)	Std (%)	Prediction	MAE (%)	Std (%)
T +3	5.93	4.23	T+45	12.87	10.23
T+9	9.12	8.91	T+51	10.97	10.92
T+15	9.92	8.04	T+57	13.82	9.61
T+21	9.39	7.28	T+63	11.88	9.95
T+27	10.35	6.41	T+69	9.56	7.68
T+33	11.81	12.24	T+75	10.83	9.32
T+39	11.63	7.79	T+81	6.37	6.19
T+42	11.49	10.06	T+84	10.57	8.78

Conclusions

- The accuracy of the prediction model depends highly on its predictors – weather forecasting data; The more accurate the weather forecasting data, the better prediction performance the performance model
- The performance prediction error based for the weather forecasting has no obvious tendency of increasing with the increase of the forecasting horizon

Research Outlook

Question: Can the presented results be improved?

Answer: Yes