Power Quality

Andrew Kusiak
Intelligent Systems Laboratory
2139 Seamans Center
The University of Iowa
Iowa City, Iowa 52242 - 1527
andrew-kusiak@uiowa.edu
Tel: 319-335-5934 Fax: 319-335-5669
http://www.icaen.uiowa.edu/~ankusiak

Outline

- ✓ Power ramps
- ✓ Reactive power
- ✓ Optimization power quality
- ✓ Conclusion

Power Ramps

- ✓ Variable winds
- ✓ Different horizons wind farm power – time function, e.g.:
  - weeks
  - days
  - hours (of interest at present time)
  - minutes

Definition

- ✓ *PRR* (Power ramp rate): measure of the degree of the power change during a certain time interval

$$PRR = \frac{P(t+T) - P(t)}{T} \quad \text{[kW/min]}$$

$$PRR = \frac{P(t+T) - P(t)}{T \times NPP} \times 100\% \quad \text{[\%/min]}$$

- ✓ t is the current time
- ✓ T is the time interval of the power change
- ✓ *NPP* (nameplate power) is the power of the wind farm

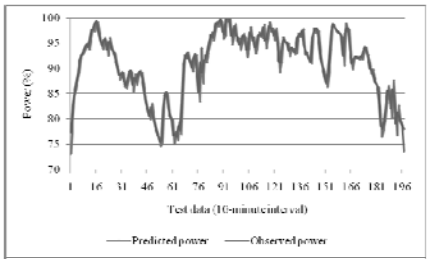
Data Description

- ✓133.5 MW rated power wind farm
- ✓SCADA collected data is stored at 10-minute intervals (10-minute average data)
- ✓ Model built of 3568 data points
- ✓ Tested on 887 data points

Data Description

Data set	Start Time Stamp	End Time Stamp	Description
1	1/1/06 1:40 AM	1/31/06 11:50 PM	Total data set; 4455 observations
2	1/1/06 1:40 AM	1/25/06 8:00 PM	Training data set; 3568 observations
3	1/25/06 8:10 PM	1/31/06 11:50 PM	Test data set; 887 observations

T + 10 Min Power Prediction (10-min Ahead Predictions)



Metrics Used in PRR Prediction

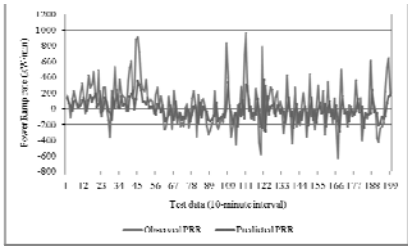
- AE: Absolute error

$$AE = |y - \hat{y}|$$

- y is the observed PRR, $\hat{y}$ is the predicted PRR

Units: kW/min or %/min

T + 10 min PRR Prediction (10-min Ahead Predictions)



The unit of PRR is kW/min (135.5 MW rated power)

Statistics for PRR of Top 15% of Wind Farm Capacity

AE	kW/min	%/min
Mean	191.701	0.1435957
Std	183.894	0.1377486
Max	1091.341	0.8174832
Min	0.016	0

AE = Absolute Error (135.5MW rated power)

Statistics for PRR of Mid-range 20% of Wind Farm Power

AE	kW/min	%/min
Mean	467.627	0.351
Std	481.195	0.361
Max	3556.387	2.664
Min	8.131	0.006

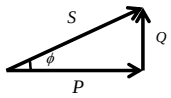
AE = Absolute Error (135.5 MW rated power)

Summary

- ✓The results presented were prepared in a short time for illustrative purposes
- ✓ The results presented can be greatly improved
- ✓ Confidence index is possible to develop

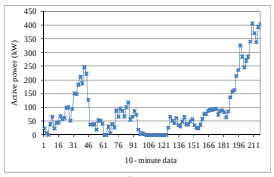
Power Quality

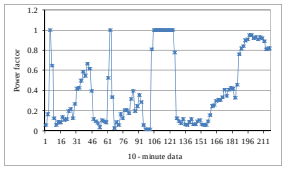
$$PF = \frac{P}{S}$$
$$S^2 = P^2 + Q^2$$
$$P = S\left|\cos\phi\right|$$

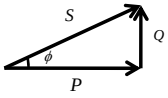


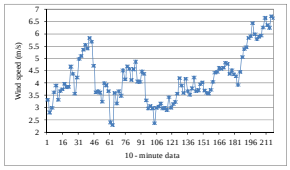
- ✓ PF: power factor; P: active power measured in W (Watts);
- ✓ S: apparent power measured in volt-amperes (VA);
- ✓ Q: reactive power measured in reactive volt-amperes (Var);
- ✓ ϕ: phase angle between current and voltage.

Power Factor









Power quality improvement

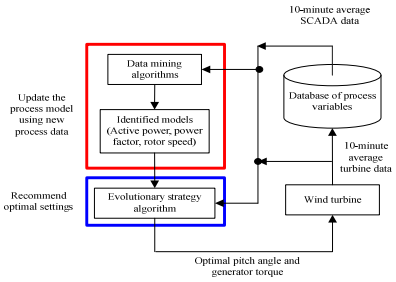
- Power factor is a comprehensive metric to power quality.
- The controllable variables of wind turbine adjust the generator load, and thus the low power factor could be increased, then the power factor impacts the harmonic distortion and transient overvoltage in the power system.
- The ideal goal of wind turbine is to set power factor as one or unit power factor; however, power factor is hard to control, and thus it is usually far below one in electricity industry.

Metrics for dynamic models

$$AE = \left|\hat{y} - y\right| \qquad MAE = \frac{\sum_{i=1}^{N} AE(i)}{N} \qquad Std = \sqrt{\frac{\sum_{i=1}^{N} (AE(i) - MAE)}{N-1}}$$

- $\hat{y}$: predicted corresponding parameters;
- y : observed values of corresponding parameters, and they could be the active power, power factor and rotor speed;
- N : the number of test data points used to validate the performance of the dynamic MISO models;
- The small value of the MAE and Std implies a superior prediction performance of the wind turbine models.

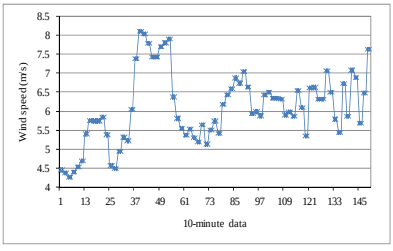
Optimization framework



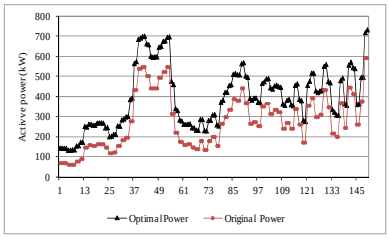
Data description

Data set	Start Time Stamp	End Time Stamp	Description
1	7/01/08 12:00 AM	7/31/08 11:50 PM	Total data set; 4466 observations
2	7/01/08 12:00 AM	7/24/08 12:00 AM	Training data set; 3457 observations
3	7/25/08 12:10 AM	7/31/08 11:50 PM	Test data set; 1009 observations

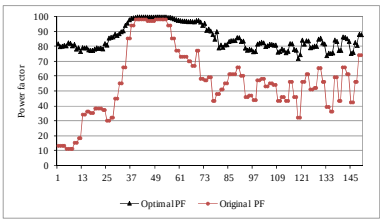
Low wind speed scenario



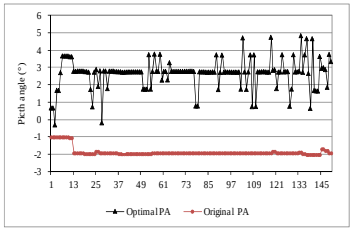
Optimal vs original active power



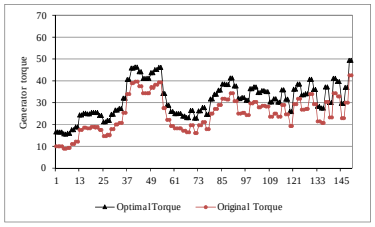
Optimal vs original power factor



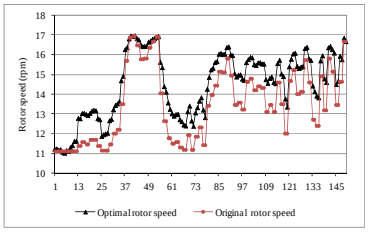
Optimal vs original blade pith angle



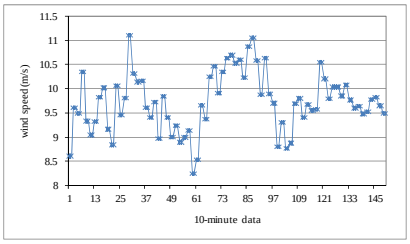
Optimal vs original generator torque



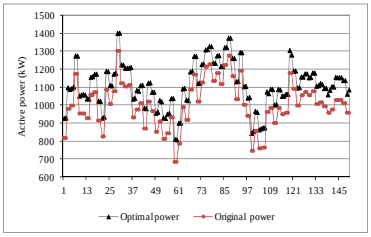
Optimal vs original rotor speed



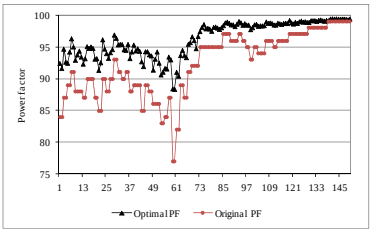
High wind speed scenario



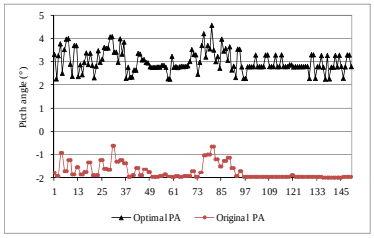
Optimal vs original power output



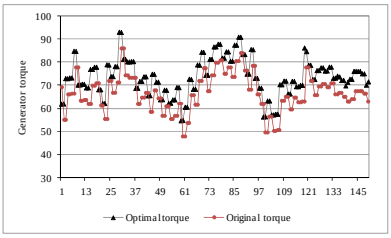
Optimal vs original power factor



Optimal vs original pitch angle



Optimal vs original generator torque



Optimal vs original rotor speed