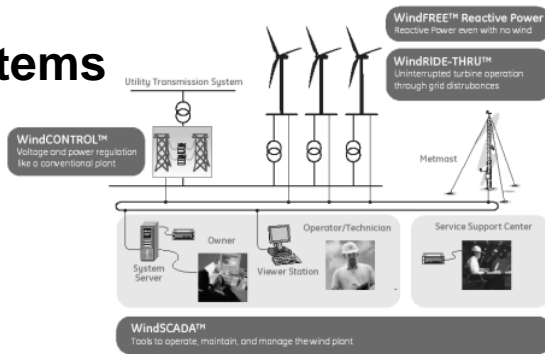


GE Energy

Wind Plant Systems

- **Grid Integration**
- **Plant and Turbine Controls**
- **SCADA**



Mahesh Morjaria
Manager, Wind Plant Systems Platform



imagination at work

Adopted for
Wind Power Management class
http://www.icaen.uiowa.edu/~ie_155/
by
Andrew Kusiak
Intelligent Systems Laboratory
2139 Seamans Center
The University of Iowa
Iowa City, Iowa 52242 – 15227
andrew-kusiak@uiowa.edu
Tel: 319-335-5934 Fax: 319-335-5669
<http://www.icaen.uiowa.edu/~ankusiak>

Agenda

- ***Grid Friendly Wind Plant***
- ***Wind Plant Controls***
- ***SCADA System***

What makes a Wind Plant “Grid Friendly”?

- Does not trip during Faults and other System Disturbances ... *ride through capability*
- Regulates Plant Voltage and Power
- Limits the Rate of Change of Power from Variations in Wind Speed ... *Ramp Rate Control*
- Reacts to Changes in Grid Frequency ... *Frequency Droop*
- Controls the Insertion and Removal of Large Power Blocks ... *Startup and Shutdown Control*
- Provides Reactive Power When Needed ... *Wind Free Reactive Power*

Grid Fault Tolerance

Low Voltage Ride Through

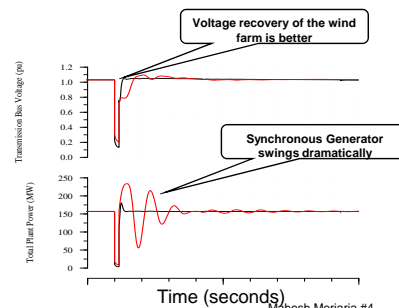
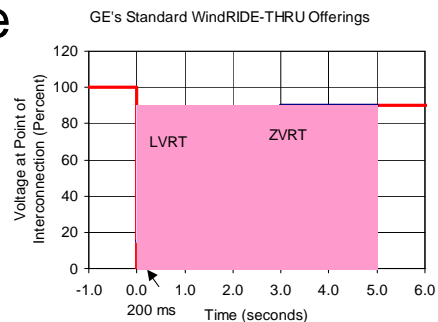
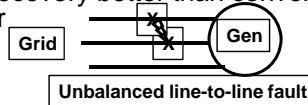
- > Required by grid codes
- > Improves gearbox life

Zero Voltage Ride Through

- > Required by FERC after 12/31/07
- > New controls for unbalanced faults
- > GE 1.5 and 2.5 will comply

Fault Recovery

- > Voltage recovery better than conventional generator



Low Voltage Ride Through Capability

Low voltage ride through (LVRT) is a turbine capability when the voltage in the grid drops due to a fault or load change in the grid.

The severity of the voltage dip is defined by the voltage level during the dip (may go down to zero) and the duration of the dip.

Depending on the application the device may, during and after the dip, be required to:

- ✓ Disconnect temporarily from the grid, but reconnect and continue operation after the dip
- ✓ Stay operational and not disconnect from the grid
- ✓ Stay connected and support the grid with reactive power



Maresh Morjaria #5
March 3, 2009

Power Droop

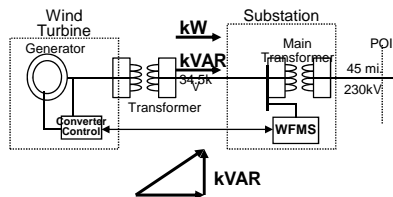
- ✓ When circuit activity changes abruptly, it can cause a sudden drop or rise in power supply voltage.
- ✓ This change is known as power droop and is an instance of power supply noise.
- ✓ Power droop can cause an IC to fail.
- ✓ Such failures should be screened during testing
- ✓ Evaluation of the worst-case power drop by accumulating the high- and low-frequency effects.



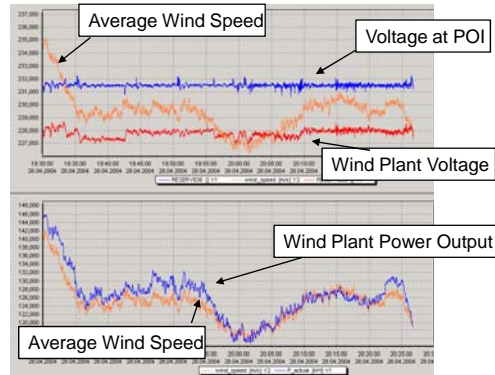
Maresh Morjaria #6
March 3, 2009

Voltage Regulation

- Regulates Grid Voltage at Point of Interconnection
- Minimizes Grid Voltage Fluctuations Even Under Varying Wind Conditions



Actual measurements from a 162MW wind plant



Voltage Regulation Like A Conventional Power Plant

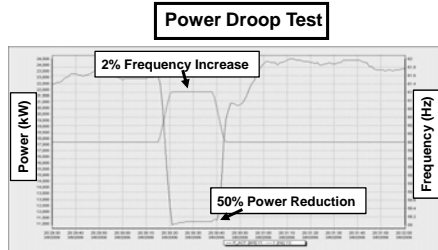
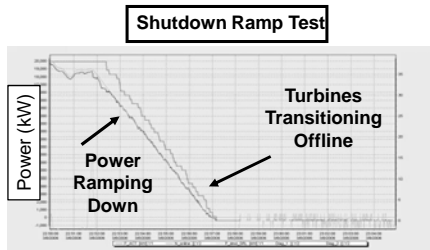
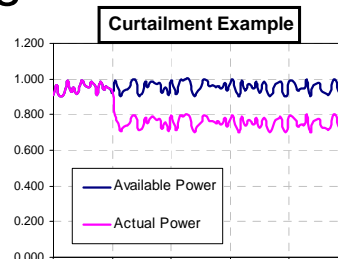


Maresh Morjaria #7
March 3, 2009

Active Power Controls

Typical Grid Requirements

- > Ramp rates
- > Power curtailment
- > Power drop w/ frequency



Maresh Morjaria #8
March 3, 2009

WindFREE Reactive Power

- Wind Turbine converter can deliver reactive power (kVAR) without wind (kW)
- Benefits weak grids and systems with high wind penetration
- Voltage support continues without active power generation ... even following trips

Reactive Power - *even without wind*



Maresh Morjaria #9
March 3, 2009

Agenda

- ***Grid Friendly Wind Plant***
- ***Wind Plant Controls***
- ***SCADA System***

Wind Plant SCADA System

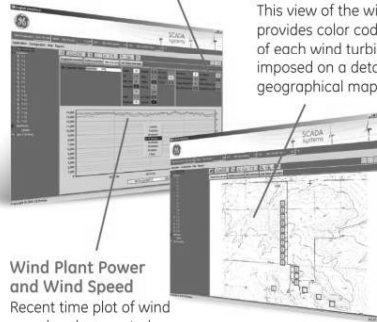
- Real-time operational control of each turbine & complete Wind Plant
- Historical data base with comprehensive reporting system including Production and Wind reports
- Secure User-Access, intuitive Operation & Maintenance tool

Wind Plant Status

Color coded summary of how many wind turbines are in each mode.

Graphical Overview of Wind Plant

This view of the wind plant provides color coded status of each wind turbine super-imposed on a detailed geographical map.



Wind Plant Power and Wind Speed

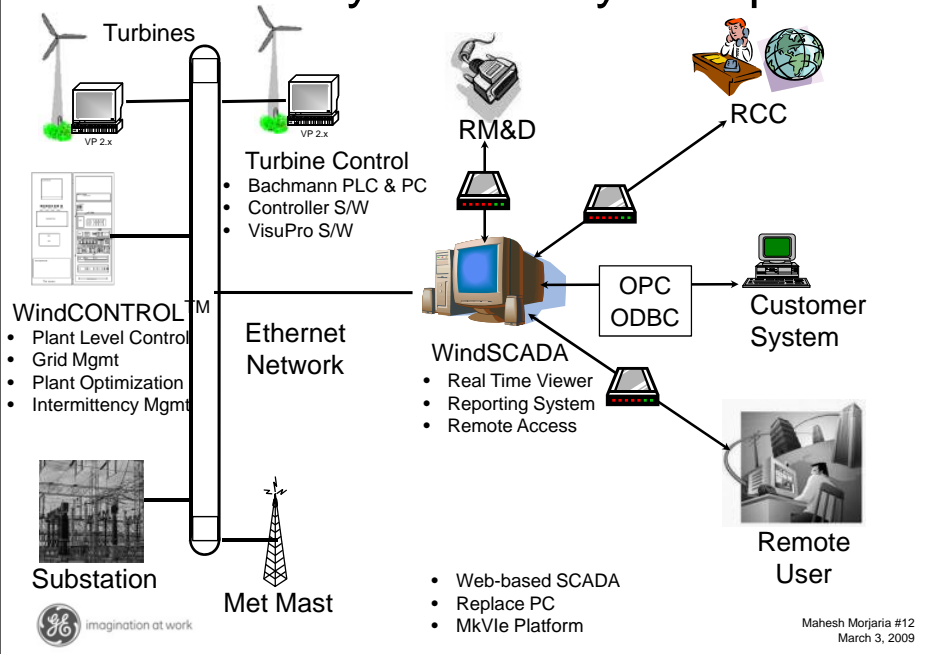
Recent time plot of wind speed and generated power.

Tools to operate, maintain and manage the wind plant



Mahesh Morjaria #11
March 3, 2009

Wind Plant Systems Key Components



Mahesh Morjaria #12
March 3, 2009

Plant Level SCADA System

The screenshot displays the GE SCADA systems interface for a plant level. The main window shows a 3D cutaway model of a turbine with various components labeled. The interface includes a top navigation bar with 'English Interface', 'SCADA systems', and 'Site Power'. Below this, there are several panels: a left sidebar with a tree view of turbines (Turbine 1-25), a central 'Current Data' panel with 'Operational data' and 'Control' tabs, and a right panel with 'Online Report' and 'Parameter' tabs. A status bar at the bottom shows 'Substation Production MTD: 6.487 MWh' and 'Site Inlet Speed: 7.2 m/s'. The GE logo and 'imagination at work' tagline are visible in the bottom left corner.


#13
009

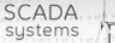
Plant Level SCADA System

This screenshot shows a detailed data table within the GE SCADA systems interface. The table lists performance metrics for various turbines over time. The columns include 'TimeSpan', 'A_ST', 'A_TOWER', 'RL1_ACT', 'RL1_SET', 'RL2_ACT', 'RL2_SET', 'RL3_ACT', 'RL3_SET', and 'CRCL'. The data rows show values for different turbines (e.g., 682006) across multiple time spans (e.g., 682006, 682007, 682008).

| TimeSpan | A_ST | A_TOWER | RL1_ACT | RL1_SET | RL2_ACT | RL2_SET | RL3_ACT | RL3_SET | CRCL | |
|----------|------|---------|----------|----------|----------|----------|----------|----------|----------|----|
| 682006 | 100 | 143 | 3.239999 | 3.539999 | 3.539999 | 3.539999 | 3.539999 | 3.539999 | 14 | |
| 682006 | 109 | 163 | 3.460000 | 3.460000 | 3.460000 | 3.460000 | 3.460000 | 3.460000 | 14 | |
| 682006 | 113 | 143 | 2.840000 | 2.75 | 2.789999 | 2.75 | 2.710000 | 2.75 | 14 | |
| 682006 | 121 | 183 | 2.400000 | 2.220000 | 2.539999 | 2.220000 | 2.329999 | 2.220000 | 14 | |
| 682006 | 136 | 183 | 2.549999 | 3.829999 | 2.849999 | 1.829999 | 1.829999 | 2.100000 | 1.829999 | 14 |
| 682006 | 141 | 173 | 1.860000 | 2.029999 | 1.879999 | 2.029999 | 1.840000 | 2.029999 | 14 | |
| 682006 | 143 | 178 | 2.329999 | 2.619999 | 2.430000 | 2.819999 | 2.380000 | 2.619999 | 14 | |
| 682006 | 148 | 174 | 3.089999 | 3.329999 | 3.009999 | 3.329999 | 3.150000 | 3.329999 | 14 | |
| 682006 | 147 | 177 | 4.139999 | 4.299999 | 3.980000 | 4.299999 | 3.810000 | 4.299999 | 14 | |
| 682006 | 148 | 180 | 4.719999 | 4.840000 | 4.640000 | 4.849999 | 4.699999 | 4.840000 | 14 | |
| 682006 | 142 | 150 | 5.199999 | 5.340000 | 5.180000 | 5.340000 | 5.180000 | 5.340000 | 14 | |
| 682006 | 143 | 154 | 5.480000 | 5.489999 | 5.480000 | 5.489999 | 5.25 | 5.489999 | 14 | |
| 682006 | 135 | 183 | 5.559999 | 5.480000 | 5.630000 | 5.480000 | 5.489999 | 5.480000 | 14 | |
| 682006 | 122 | 156 | 5.339999 | 5.389999 | 5.530000 | 5.339999 | 5.550000 | 5.389999 | 14 | |
| 682006 | 116 | 156 | 5.380000 | 5.150000 | 5.349999 | 5.150000 | 5.190000 | 5.150000 | 14 | |
| 682006 | 110 | 155 | 4.800000 | 4.809999 | 5.339999 | 4.809999 | 4.809999 | 4.809999 | 14 | |
| 682006 | 105 | 143 | 4.780000 | 4.869999 | 4.890000 | 4.869999 | 4.820000 | 4.869999 | 14 | |
| 682006 | 98 | 156 | 4.780000 | 4.800000 | 4.730000 | 4.800000 | 4.809999 | 4.800000 | 14 | |
| 682006 | 97 | 178 | 4.710000 | 4.730000 | 4.829999 | 4.730000 | 4.730000 | 4.730000 | 14 | |
| 682006 | 101 | 170 | 4.349999 | 4.130000 | 4.280000 | 4.130000 | 4.300000 | 4.130000 | 14 | |

3.X Reporting System – Advanced Reports






Next Gen Reporting

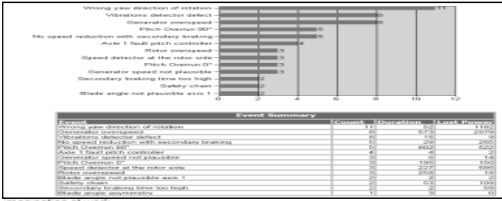
- ✓ Higher level processing ... actionable information
- ✓ Web based Reporting
- ✓ Scheduled Reports
- ✓ Multiple Language Capable

Park Efficiency

Start Time: 10/1/2006 10/31/2006 11:16:44 AM
 End Time: 10/15/2006 Execution Time: 5 second(s)



| System | Windspeed (m/s) | Power (kW) | Capacity Factor (%) | Delivered Energy (MWh) | Expected Energy (MWh) | Performance Ratio (%) | System OK Time (hrs) | Availability (%) |
|----------------|-----------------|------------|---------------------|------------------------|-----------------------|-----------------------|----------------------|------------------|
| WTG 1 | 7.7 | 458 | 28 | 145.2 | 166.0 | 87 | 318 | 96.4 |
| WTG 2 | 7.3 | 508 | 32 | 163.4 | 150.9 | 108 | 321 | 97.7 |
| WTG 3 | 7.6 | 566 | 35 | 181.3 | 165.8 | 109 | 321 | 97.5 |
| WTG 4 | 7.8 | 513 | 32 | 163.3 | 174.3 | 94 | 322 | 97.5 |
| WTG 5 | 7.9 | 552 | 34 | 175.8 | 184.8 | 95 | 321 | 97.6 |
| Summary | 7.6 | 519 | 32 | 828.9 | 841.9 | 98 | 1605 | 97.4 |



Pareto chart of trip events

Provides trip counts, outage duration and lost energy

Maresh Morjaria #15
March 3, 2009

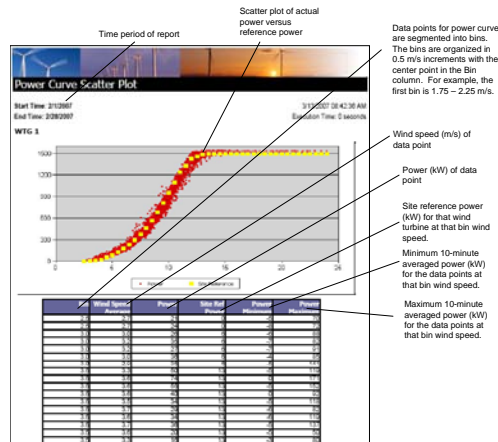
Web Based Reporting System – Available Reports

Operational Reports

- Operational Data
- Meter Reading
- Plant Efficiency
- UPE Due to Curtailment
- Performance
- Grid
- Power Curve Line Plot
- Power Curve Line Plot Comparison
- Power Curve Scatter Plot
- Power Curve Scatter Plot (Min/Max)
- Wind Speed Distribution

Maintenance Reports

- Historian Data Coverage
- Event Log
- Event Pareto
- Fault Analysis
- Command Log
- Parameter Change
- Inverted Input
- VP/Bachmann PLC Comm Loss
- Parameter Values



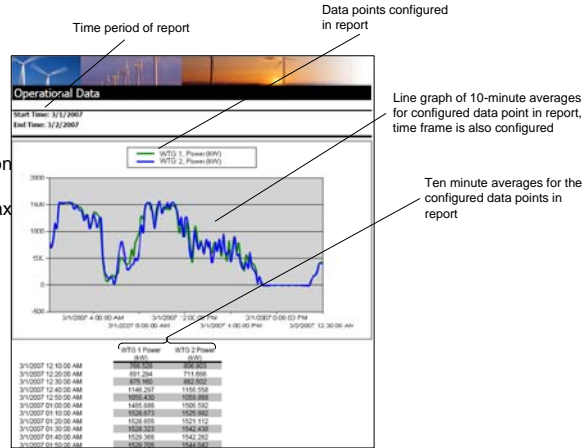
Web Based Reporting System – Available Reports

Operational Reports

- Operational Data
- Meter Reading
- Plant Efficiency
- UPE Due to Curtailment
- Performance
- Grid
- Power Curve Line Plot
- Power Curve Line Plot Comparison
- Power Curve Scatter Plot
- Power Curve Scatter Plot (Min/Max)
- Wind Speed Distribution

Maintenance Reports

- Historian Data Coverage
- Event Log
- Event Pareto
- Fault Analysis
- Command Log
- Parameter Change
- Inverted Input
- VP/Bachmann PLC Comm Loss
- Parameter Values



Mahesh Morjaria #17
March 3, 2009

Backup Material



Mahesh Morjaria #18
March 3, 2009

First SCADA Users' Group Mtg at AWEA Conference

Participants

- 14 users from FP&L, AEP, Brookfield Power, Horizon Energy, enXco, AES

Agenda

- SCADA development plans
- Test drive of web-based reporting and ESS operational web pages with user surveys
- Feedback Sessions

Customer Feedback:

- Browser based tools preferred, FPL has nine different SCADA packages across fleet ... *migration to Web-based tools*
- Connectivity to third party systems (OSI-PI, Second Wind, customer systems) a plus relative to other vendors ... *open architecture*
- Increased user configurability & flexibility
- Reports get customized at each site ... *Excel export capability key*
- Users appreciated opportunity to provide inputs, look forward to next year's event
- **Need upgrade for their existing SCADA s/w**

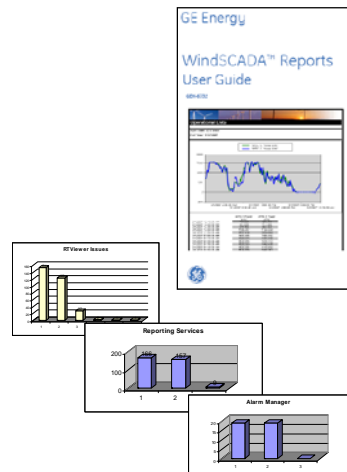


Mahesh Morjaria #19
March 3, 2009


WindSCADA Version 3.0 Released (June 2007)

Key Features:

- Web-based Reporting with improved performance
- Built-in export capability (Excel, PDF, XML etc)
- Improved Product Documentation
- Fixed major software bugs of previous version



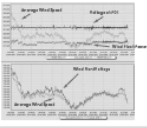
Mahesh Morjaria #20
March 3, 2009



"Grid Friendly" Wind Power Plant

WindCONTROL – Wind Plant Controller

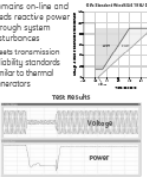
- Regulates grid voltage at point of interconnection
- Minimizes grid voltage fluctuations even under varying wind conditions
- Regulates total wind plant active & reactive power through control of individual turbines
- Provides start-up & shutdown control
- Provides frequency droop control



Controls Wind Plant Like a Conventional Power Plant

Wind RIDE-THRU – A Zero/Low Voltage Ride Thru

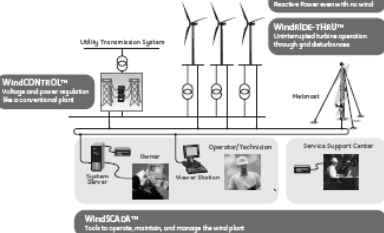
- Remains on-line and feeds reactive power through system disturbances
- Meets transmission reliability standards similar to thermal generators



Uninterrupted turbine operation through grid disturbances

What makes a Wind Plant "Grid Friendly"?

- Does not trip during faults and other system disturbances ...ride through capability
- Regulates plant voltage and power
- Limits the rate of change of power due to variations in wind speed ...ramp rate control
- Reacts to changes in grid frequency ... frequency droop
- Controls the insertion and removal of large power blocks ...start-up and shutdown control
- Provides reactive power when needed ...wind-free reactive power
- Provides plant wind operation and maintenance system



WindCONTROL™
Voltage and power regulation like a conventional plant

WindFREE™ Reactive Power
Reactive Power even without wind

WindRIDE-THRU™
Uninterrupted turbine operation through grid disturbances

WindSCADA™
Tools to operate, maintain, and manage the wind plant

- Addresses reliability concerns of grid operators
- Improves grid operability and security
- Increases capability of grids to successfully achieve high levels of wind penetration

Engineering Award Winner for Outstanding Technical Innovation


WindFREE Reactive Power

- Wind turbine converter can deliver reactive power (VAR) without wind (MW)
- Benefits weak grids and systems with high wind penetration
- Voltage support continues without active power generation ... even following trips


Reactive Power – even without wind

Wind Plant SCADA System

- Real-time operational control of each turbine & complete wind plant
- Historical database with comprehensive reporting system including production and wind reports
- Secure user-access, intuitive operation & maintenance tool



Tools to operate, maintain and manage the wind plant

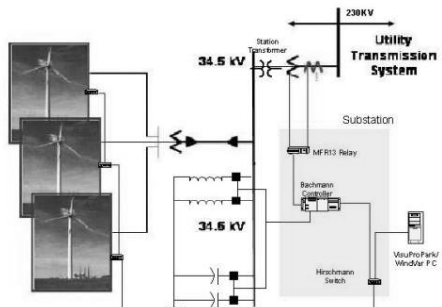

imagination at work


Mahesh Morjaria #21
March 3, 2009

WindCONTROL


Hardware Overview

- Substation Mounted Cabinet
- PT&CT Interface to Substation
- SCADA HMI
- Operates on Wind Plant LAN





Plant Level Controller Orchestrates Operation of Individual Turbines


imagination at work

Mahesh Morjaria #22
March 3, 2009