
Stanford GCEP Energy Workshop

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Power System Issues for Bulk Wind Generation: Status and Needs

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Development of Large Scale Wind Generation in the U.S.

- Confined to California until mid 1990's
- Large plants now operating in many control areas
 - Great Plains (MN, IA)
 - Texas
 - Pacific Northwest
- Changing "utility" perspectives
 - Installed capacity forecast to grow significantly
 - Influence on behavior of grid can no longer be ignored
 - System-level impacts will likely need to be addressed as wind capacity increases
- Power industry evolution creates turbulent backdrop
 - Competitive markets
 - New organizations and alliances
 - New business practices
 - "New" emphasis on reliability

Fundamental Power System Engineering Challenges

- Wind generation technology is **novel** relative to conventional generating equipment and systems
- Wind generation is an **energy** resource in a **capacity** world
- Experience with wind generation is nonexistent compared with conventional resources

Engineering Practice for Large Power Systems

- Based on computer tools and computational techniques for “predicting” performance and behavior – no “plug and play”
- Methods require appropriate characterization of each system element – generators, loads, transmission, etc.
- Experience also critical to understanding what system states are of most interest (what to study)

Major Categories of Power System Studies

- Interconnection
- Planning
- Forensic
- Special

Present Focus

- Interconnection Evaluations
 - Mandated for connection of any new element to grid
 - Must evaluate:
 - Voltage control / reactive power management
 - Thermal considerations / equipment ratings
 - Short-circuit behavior
 - Large-signal dynamic behavior
 - Reliability / security
- Integration Studies
 - Increasing concern as wind generation capacity in a given control area grows
 - Focuses on the normal operation of the system
 - Voltage regulation and frequency control
 - Short-term system planning and scheduling
 - Transmission utilization and congestion issues
 - Influence on overall production cost
 - Ancillary services
 - Market influences and impacts

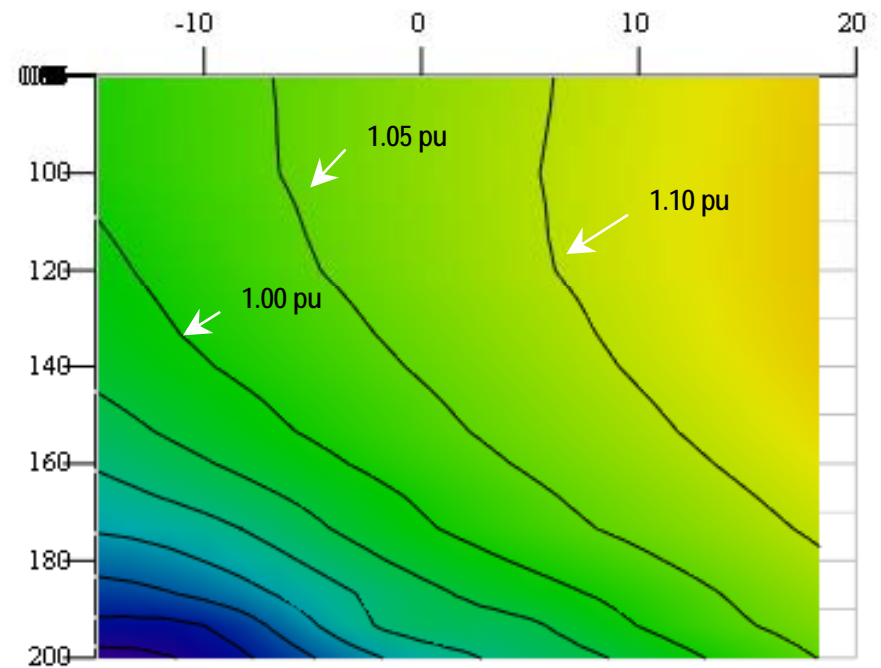
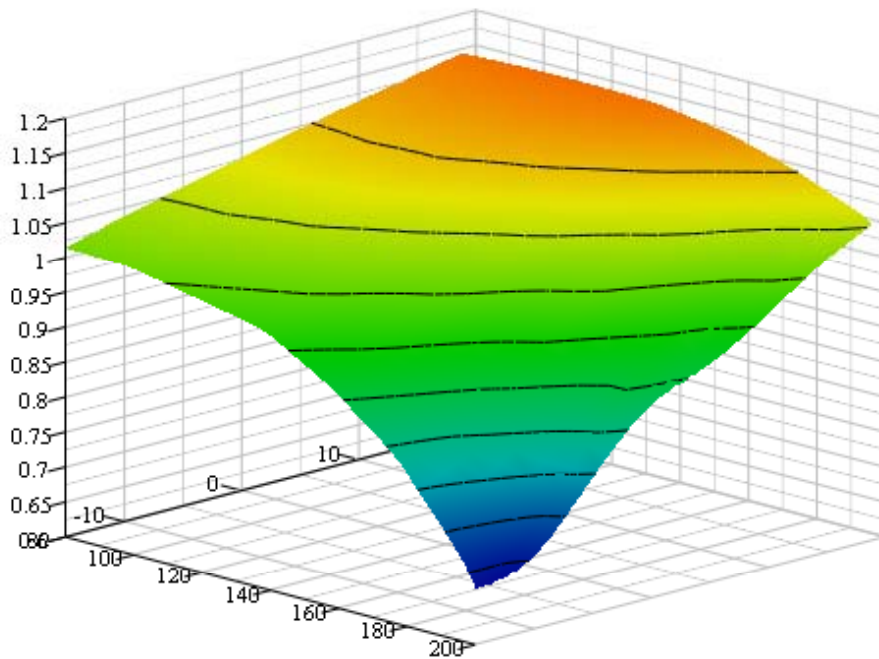
Modeling Challenges for Wind Generation

- Uneasy “fit” with conventional tools
 - induction machines rather than synchronous generators
 - “novel” control technology – e.g. flux-vector control of induction machines
 - Unfamiliar mechanical system & prime mover
 - Many small generators vs. few large generators
 - Expansive plant electrical system
- Unique operational characteristics
 - Not dispatchable
 - More difficult to identify appropriate “states” to be analyzed

Interconnection Challenges for Wind Generation

- Remote facilities
 - Typically interconnection to weak transmission network
 - Designs can be challenging
- Reactive power management
 - Critical for controlling voltage
 - Dynamic character of wind generation
 - Reactive power planning for network must be coordinated with wind plants
- Interconnection requirements are evolving
 - Were typically very simple
 - Evolving to voltage control, dynamic reactive power management

Wind Plant Interconnect Bus Voltage as function of P and Q for Weak Network



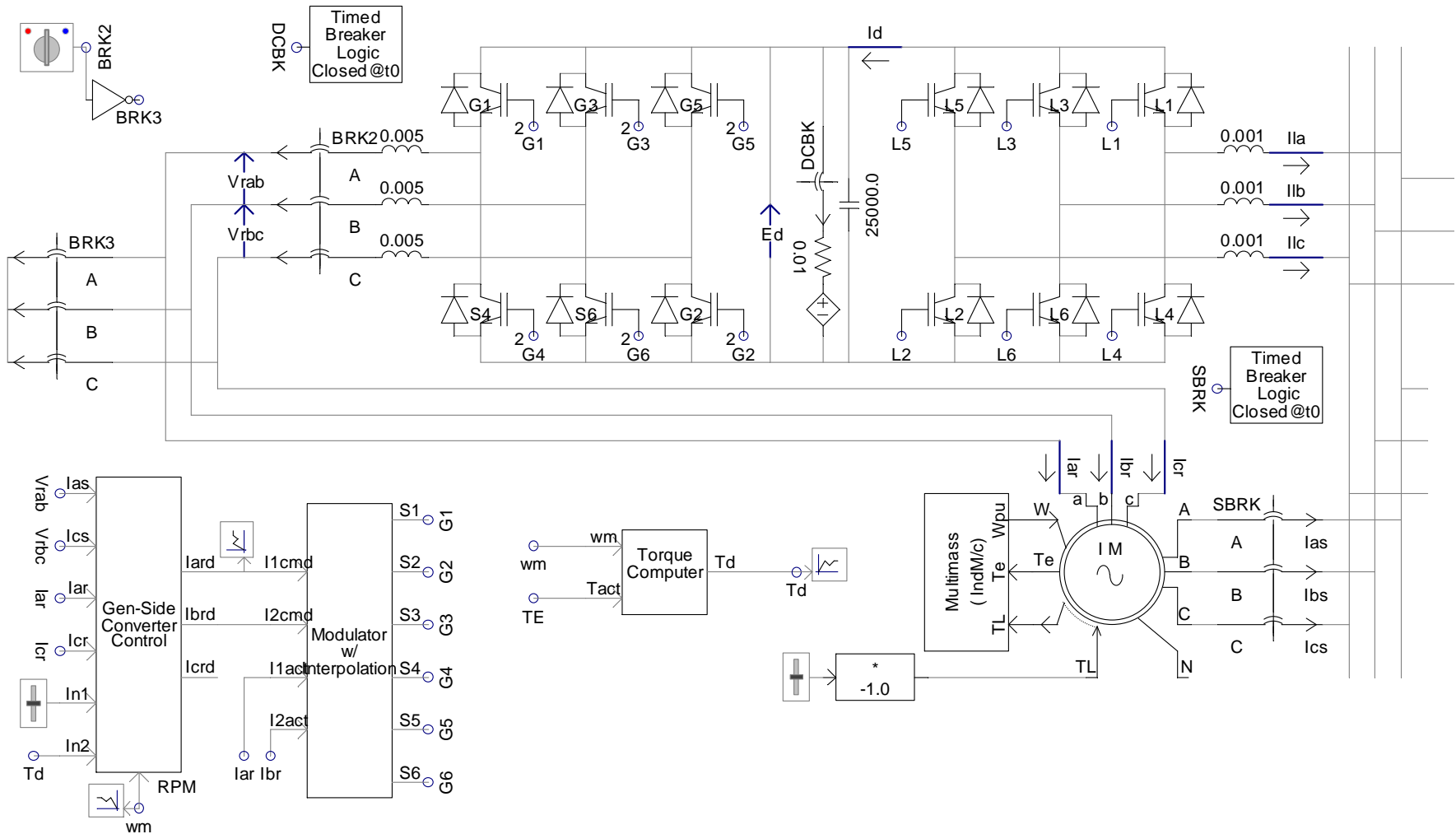
Evolving Interconnection Requirements are driving Wind Technology Development

- More robust turbine designs
 - Low-voltage ride-through
 - More desirable dynamic response characteristics
- Better wind plant designs
 - Plant-level planning of reactive compensation
 - Interconnection bus behavior within specs
 - Improved medium-voltage collector system design
- Ongoing needs
 - Validated models
 - New models
 - Experience

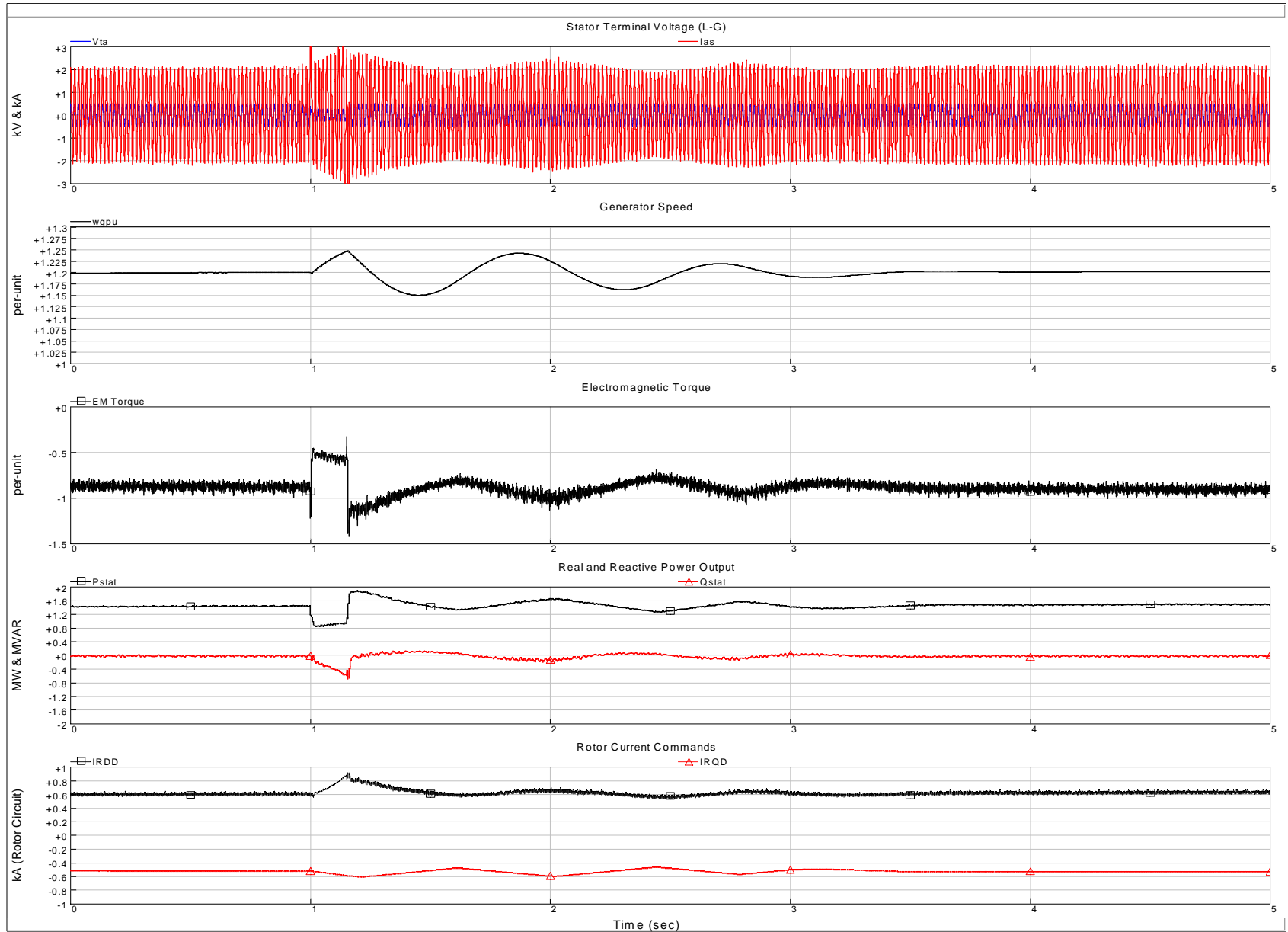
ERCOT Dynamic Model Development

- Urgent need in wind and power industries for models
- ERCOT took industry lead in addressing issue
- Launched 12-month effort to develop and validate dynamic windplant models for PSS/E platform
- Project began late July, 2002
- Monitoring effort included to provide field data for validating models
- PSS/E user models delivered September, 2003

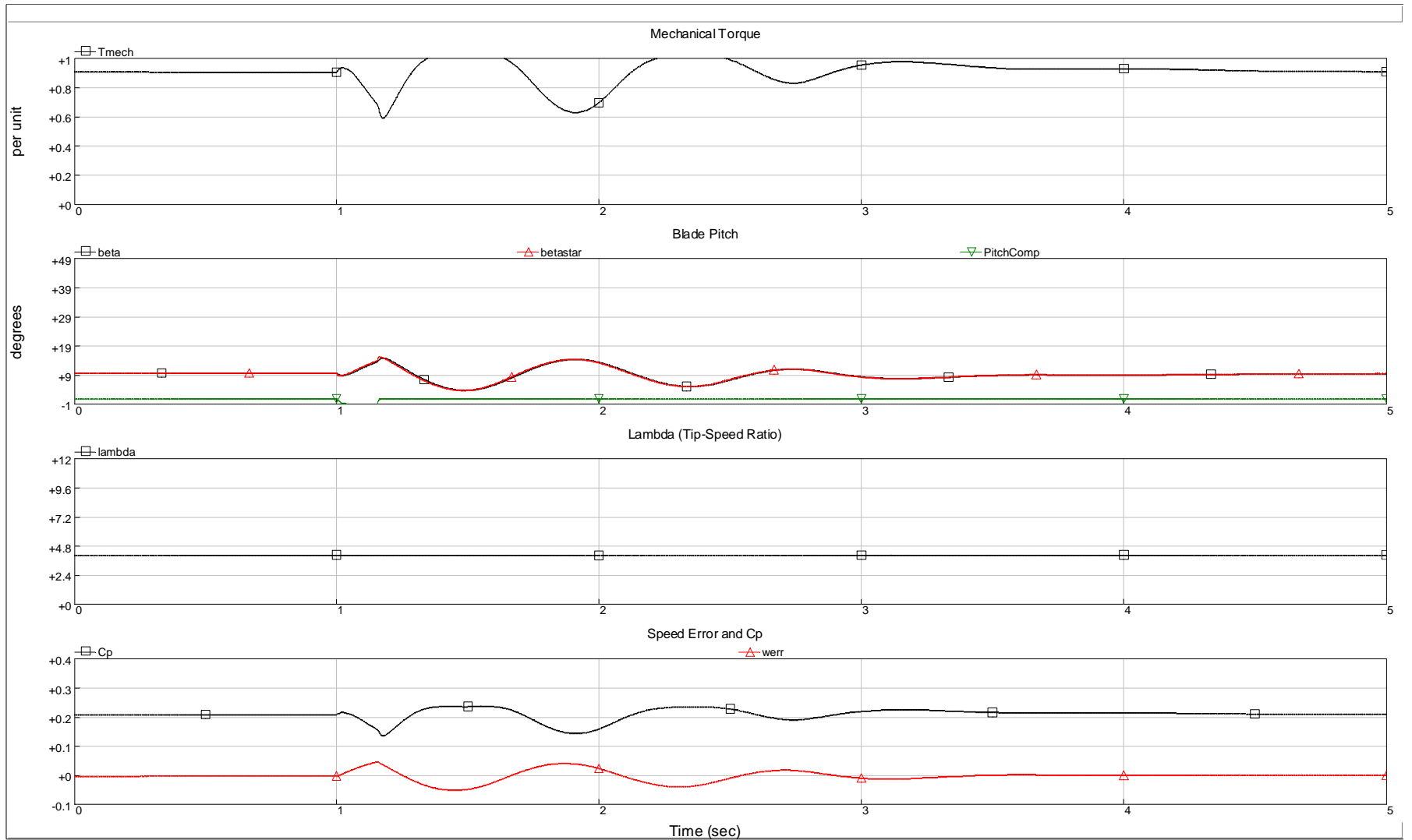
GE Wind 1.5 MW – PSCAD/EMTDC Model

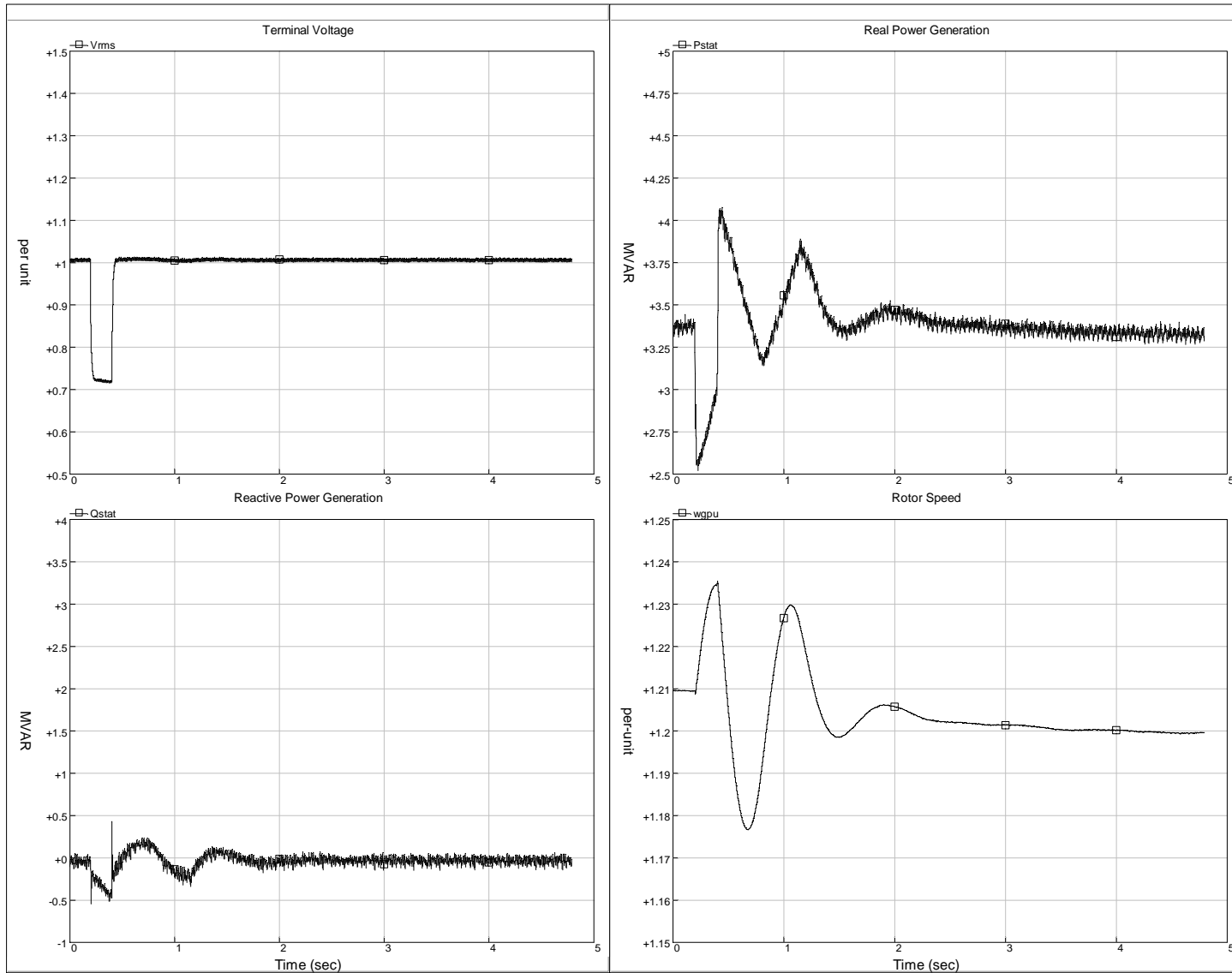


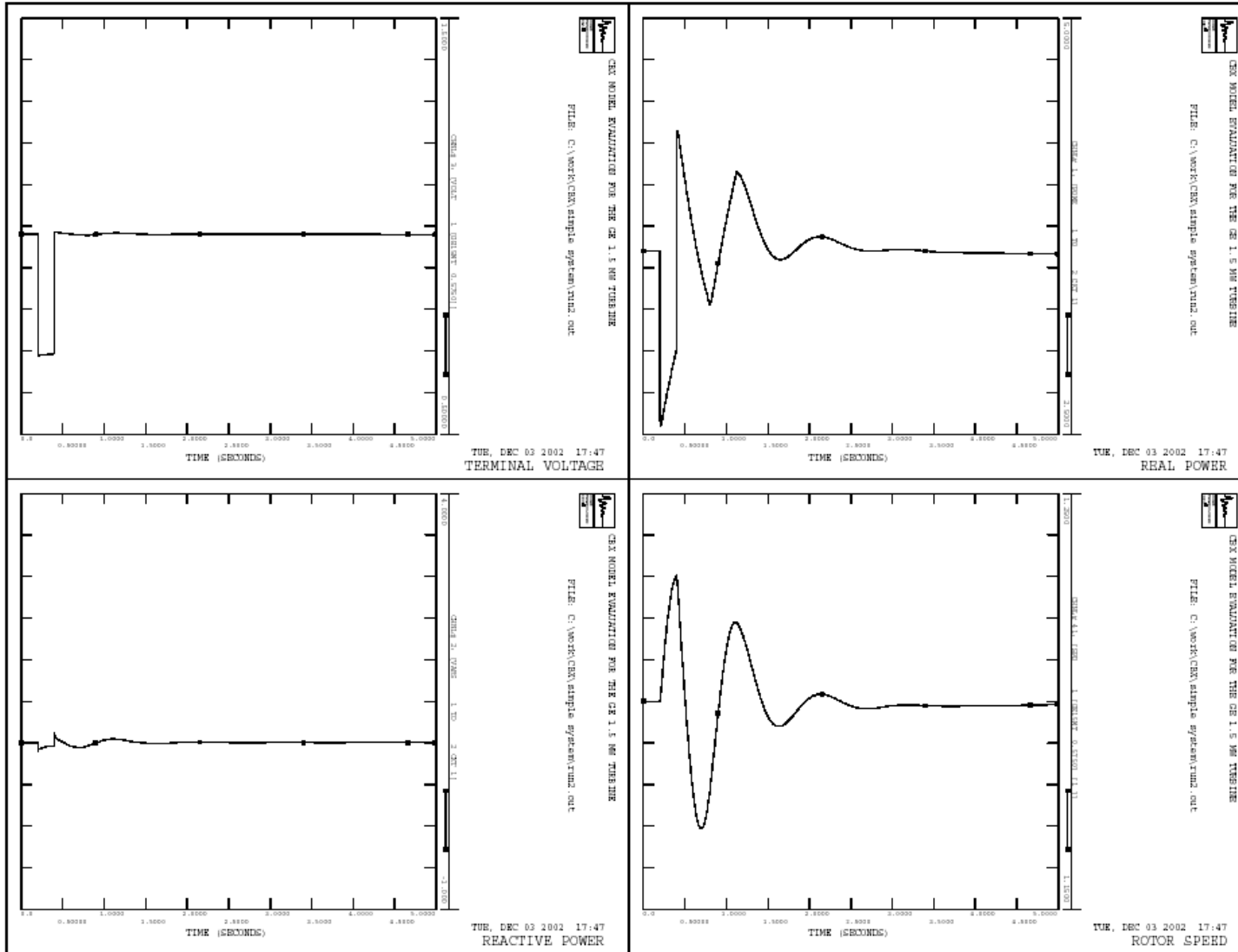
GE Wind 1.5 MW



GE Wind 1.5 MW (cont.)







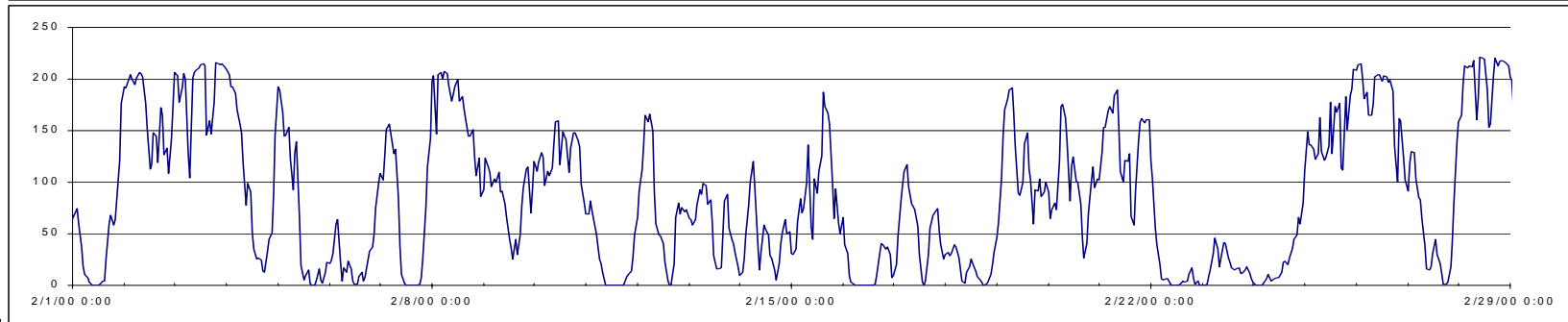
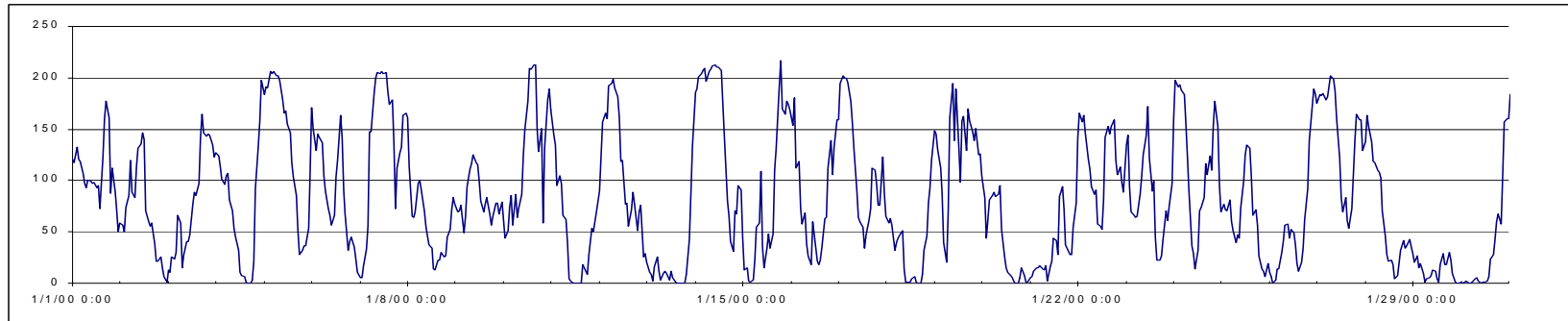
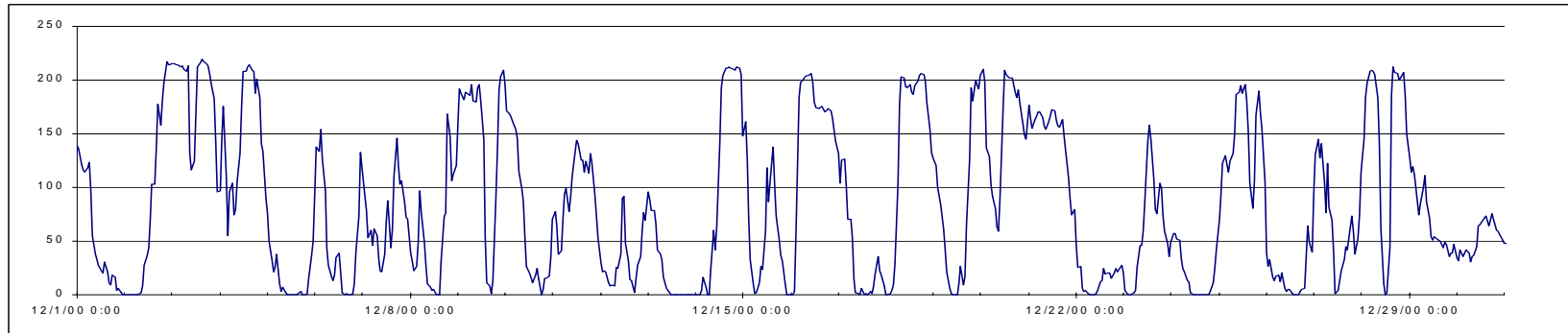
Interconnection Summary

- Early plants experienced start-up problems due to inadequate facility and interconnect design
- Lessons learned are being incorporated into new plant designs
- Significant challenges and needs remain:
 - Better characterization of wind turbine and plant performance
 - Plant and turbine modeling for power system studies not well developed
 - Models and assumptions for wind generation require validation
 - Power system engineering practice for wind plant design is still relatively immature
- Assessment
 - Playing “catch up”
 - Making progress

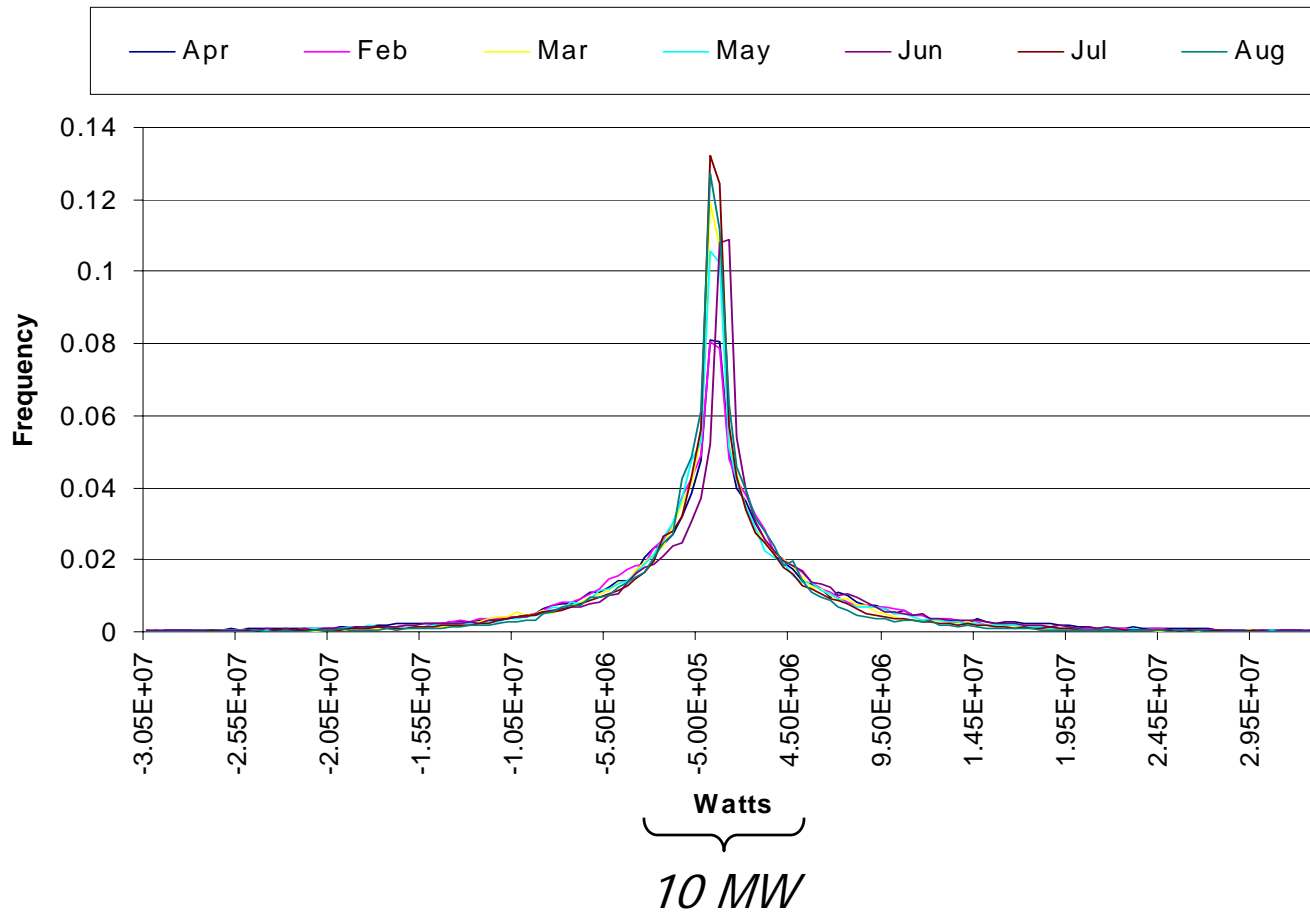
Energy vs. Capacity

- Engineering evaluations biased toward capacity
 - Design for peak conditions
 - Voltage can be related directly to power, not energy
 - Transmission capacity
- System operators deal with “MW for the hour” not MWH
 - System security and reliability linked more closely to capacity
 - Short-term operations planning and scheduling, market mechanisms utilize predictions and forecasts
- Wind generation is the ultimate “as-available” generating resource
 - Forecast power production vs. time can only be done approximately
 - Substantial amounts of as-available or non-dispatchable resources are a poor fit with tools and analytical methods for power system operation

Winter 2000 Actual Hourly Wind Generation



Output Variations of 250 MW Windplant Load-Following (minute-by-minute) time frame



Wind Generation Integration

- Definition: Quantifying the affects of the unique characteristics of wind generation on the rest of the system, markets
- Issue is increasing in importance
 - Level of concern proportional to installed wind capacity/control area capacity
 - Evolving power markets add more complexity
- Multiple studies conducted, underway
 - “screening” assessments related to RPS-driven wind generation procurements
 - Some analytical studies
 - Market-based assessments

Status: Large-Scale Grid-Connected Wind Generation

- Efforts focused on fitting wind generation into existing practice and methodologies
 - Real-time operations
 - Short-term planning, scheduling, and optimization
 - Longer-term capacity valuation
- Industry transition and conventional practice dictate current perspectives on wind energy
 - Reliability and security assessment
 - Evolution of market-mechanisms
- Long-term Barriers
 - Transmission - moving large amounts of energy long distances
 - Operations - creating structures and mechanisms that accommodate energy sources

Grid Integration Opportunities

- Transmission
 - Maximizing utilization of existing grid
 - Advanced technologies - FACTS, HVDC, higher-phase order (e.g. six-phase)
- Operations
 - Utilizing advanced technologies like forecasting
 - Sophisticated systems for real-time operations
 - New methodologies for short-term planning and scheduling
- Storage