Review of Recent Wind Integration Studies

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Research Breakthroughs:
What's needed to Accelerate Path to Market and Achieve California's 2020 Renewable Energy Goals

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Integration Studies

- Needed because wind is variable and uncertain
- Studies focus on future periods with more wind generation
- Cover many aspects of wind-based power generation
  - Transmission and reliability
  - Grid operations
  - Economics
  - Policy
- System properties influence studies
  - System size; load and footprint
  - Wind penetration; energy and capacity
  - Diversity
  - Generation fleet make up
  - Grid operation
- Many timescales involved in power systems
  - Integration studies focus on shorter time frames

Time Scales for System Planning and Operation Processes

Slower (Years)

Time Frame

Faster (seconds)

Long-Term Resource and Capacity Planning

Capacity Value

Unit-Commitment

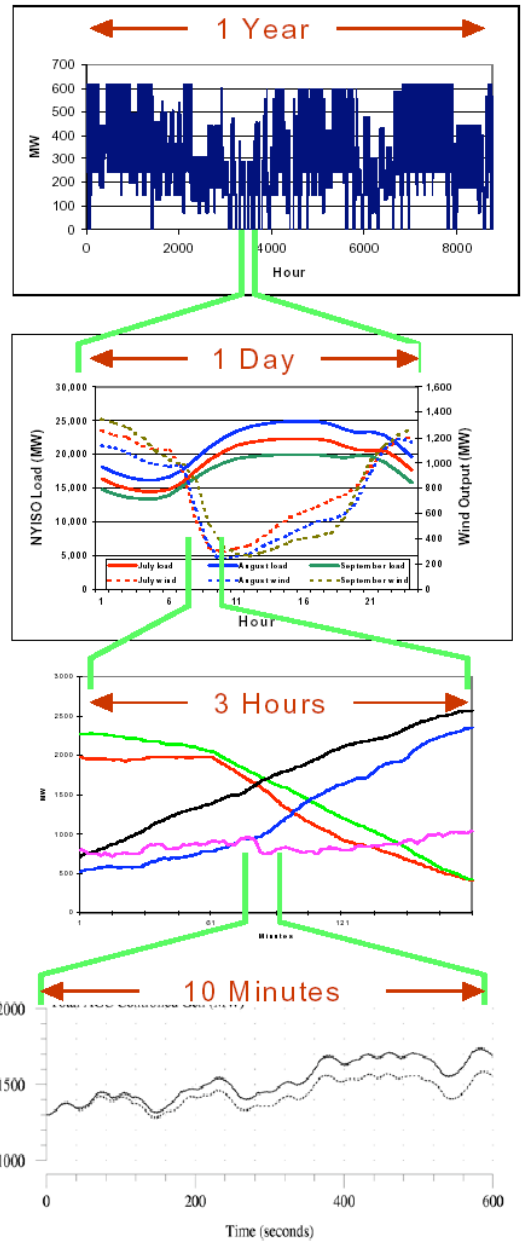
Day-Ahead Scheduling

Multi-Day Forecasting

Load-Following
(5-minute dispatch)

Hour-Ahead Forecasting

Frequency and Tie-Line Regulation (AGC)



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Integration Studies Covered

Study Name	Prepared by	Date	Peak System Load (MW)	Max. Penetration on Energy (%)	Max. Wind Capacity (MW)
Operational Impacts of Integrating Wind Generation into Idaho Power's Existing Resource Portfolio [1,2]	Enernex	Feb 07	3,085	30	1,200
Avista Corporation Wind Integration Study [3]	Enernex	Mar 07	2,100	30	600
Intermittency Analysis Project: Final Report [4,5,6]	IAP Team & GE	Jul 07	50,286	33	12,700
Arizona Public Service Wind Integration Cost Impact Study [7]	Northern Arizona University	Sep 07	7,905	10	1,260
Integration of Renewable Resources [8]	CAISO	Nov 07	50,286	20	6,700
Analysis of Wind Generation Impact on ERCOT Ancillary Service Requirements [9]	GE	Mar 08	65,000	23	15,000
20% Wind Energy by 2030 [10]	NREL	Jul 08		20	
Montana Wind Power Variability Study [11]	Genivar	Sep 08	1,766		1,450
Eastern Wind Integration and Transmission Study [12]	Enernex	Jan 10	529,857	33	225,000
Nebraska Statewide Wind Integration Study [13]	Enernex	Mar 10	7,550	40	4,727
Western Wind and Solar Integration Study [14]	GE	May 10	58,087	30	75,000

Methodologies

Statistical

- Rely on wind generation and load profiles
- Do not specifically model system or constraints
- Understand fundamental properties of wind
- Use varying time steps
- Used for studying
  - Variability
  - Ramp events
  - Extremes
  - Reserves
  - Diversity

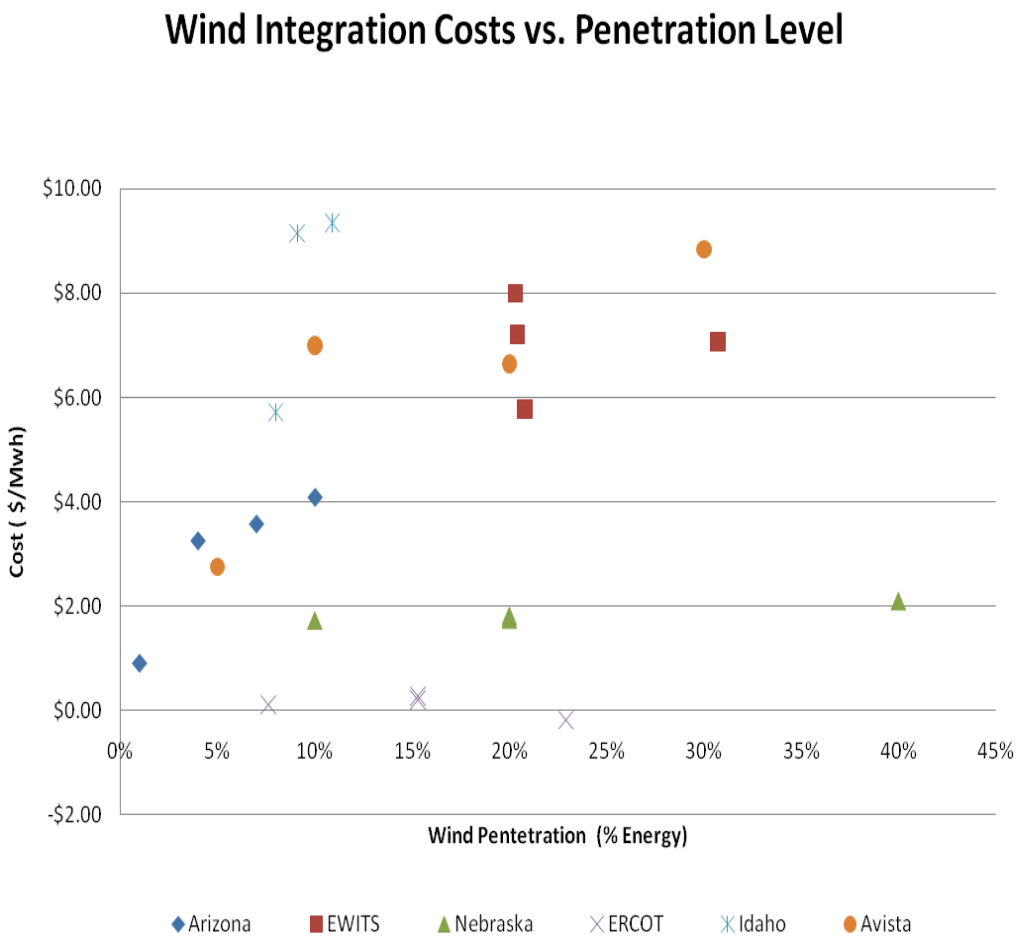
Operational

- Model aspects of system operation
- Production cost models most common
  - 8760 hour runs
- Use system constraints
- Understand how wind interacts with the system
- Used for studying
  - Costs
  - Reserves
  - Emissions
  - Unit commitment
  - Congestion

Results

- Variability
  - Magnitude of variability increases on longer timescales and with more wind capacity though not linearly
  - Ramping needs increase with wind if diurnal patterns oppose load
  - Diversity reduces the relative variability
- Energy displacement & unit commitment
  - Resource mix dependent
  - Base load least affected typically
- Reserve requirements
  - Regulation increases with penetration; magnitude of increase highly dependent on methodology
  - Variability of wind smaller driver, uncertainty larger driver of increase
- Emissions
  - NOx, SOx, CO2 reduced but magnitude of reductions depend on generation fleet
  - Emissions pricing or cap and trade further reduce emissions
- Load following and ramping
  - Depend on the variability and uncertainty of wind
  - Diurnal patterns influence load following
- Transmission and reliability
  - Location of resources impact line type and size, detailed studies needed as projects are proposed
  - Wind turbine advances allow for voltage regulation, low voltage ride through, and inertial response
  - Improved SCADA allows operators better visibility and control
- Costs

Costs



- Vary widely by study
  - Up to 9 $/MWh
- Methodology
  - Costs: fuel, operating, maintenance, congestion, transmission loss, ancillary service, etc.
- System characteristics
  - Size
  - Interconnection strength
  - Resource mix

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Managing Integration

Reduce Uncertainty

- Forecasting
  - Improved accuracy
  - Types
  - Timing
  - Granularity
- Telemetry
  - Off site measurement
  - Representative measurements
  - Reliability of measurement
- Reporting
  - Accurate availability

Increase Flexibility

- Increase reserves
- Allow renewables to provide reserves
- Energy storage
- Demand response
- Renewable curtailment
- Scheduling and dispatch changes
- Encourage flexible generation

Increase Diversity

- Renewable zones
- Balancing area cooperation
- Grid codes

Future Studies

- Sub hourly operational studies
- Extreme conditions
- Cost benefit analysis
- Transmission for proposed projects
- Import/export studies
- Regulations impacts
  - RPS, emissions price, cap and trade, etc.
- Technology
  - Smart grid, storage, distributed generation, electric vehicle

Measuring Forecast Benefits

- Goal: Isolate the effects of wind forecasts on power systems operations and evaluate benefits forecasts provide

- Model the major power system processes
  - Day ahead, hour ahead, and real time markets
  - Full California system model
  - Wide variety of system conditions
- Model wind forecasts
  - Simulate forecasts similar to current forecasts
  - Adjust simulated forecast parameters individually
- Simulate power system
  - Vary forecast parameters to isolate variables
  - Measure changes to system with different forecasts

Analysis

- Economic impacts
  - Production cost from day ahead, hour ahead, and real time
  - Congestion and loss impacts
  - Load and generation cost and revenue impacts
- Operation impacts
  - Load following and ramping needs and abilities
  - Unit commitment changes

Conclusions

- Increasing penetration of variable power sources such as wind has resulted in grid impact concerns
- Large number of recent wind integration studies were studied and compared
- Successfully integrating high penetrations isn't trivial, but it is economically feasible
- Follow-up to CEC's IAP is needed:
  - Has been 6-7 years since study (underlying data 10 years old)
  - Transmission upgrades
  - Renewable technologies have changed
  - Renewable mix has changed
  - Impact of import & export
  - Higher RPS goals are being considered

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