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Variability of Power from Distributed Wind Facilities in Montana

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Project Update

- Part 1: Wind Power Variability Analysis
  - 3 scenarios capture effect of future development plans (as proposed)
  - 3 scenarios capture effect of geospatial distribution (hypothetical)
  - Validation Complete
  - Results from all 6 scenarios presented here
- Part 2: NWE Dispatch Simulation
  - Model has been adapted from Alberta to Montana system operations
  - Testing and Validation is ongoing

Part 1: Wind Power Variability Analysis

- Objective
  - Simulate 10 minute wind power time series for a facility – GENIVAR Variability Model
  - Simulate 1 minute wind power time series for a facility – Statistical approach
  - Summarize variability of both 1-minute and 10-minute series
- Significance
  - Simulated 1-minute wind power is input to the NWE Dispatch Simulation to asses grid operation impact
- Challenge
  - Processing data

Part 1: Wind Power Variability Analysis

- Model Inputs
  - Wind speed measured at proposed development sites
  - A standard power curve for a single turbine
  - Nameplate capacity of the facility
  - Dimension of the facility

Part 1: Wind Power Variability Analysis

Methodology

- Per Norgard and Hannele Holttinen, A Multi-Turbine Power Curve Approach. Proceedings of Nordic Wind Power. Conference NWPC, 2004
- Moving Average Wind Speed
- Multi Turbine Power Curve
- Adjust annual power production
- Apply weighted moving average wind speed to Multi-Turbine Power curve for 10-minute power time series
- 1-minute power time series modeled
- Time series of individual facilities combined to generate state-wide development scenarios
- Inspect time series and summarize variability

Part 1: Wind Power Variability Analysis

- Validation
  - Validation was not performed for Montana
  - Extensive validation performed for Alberta
  - Facility Validation
  - Regional Validation

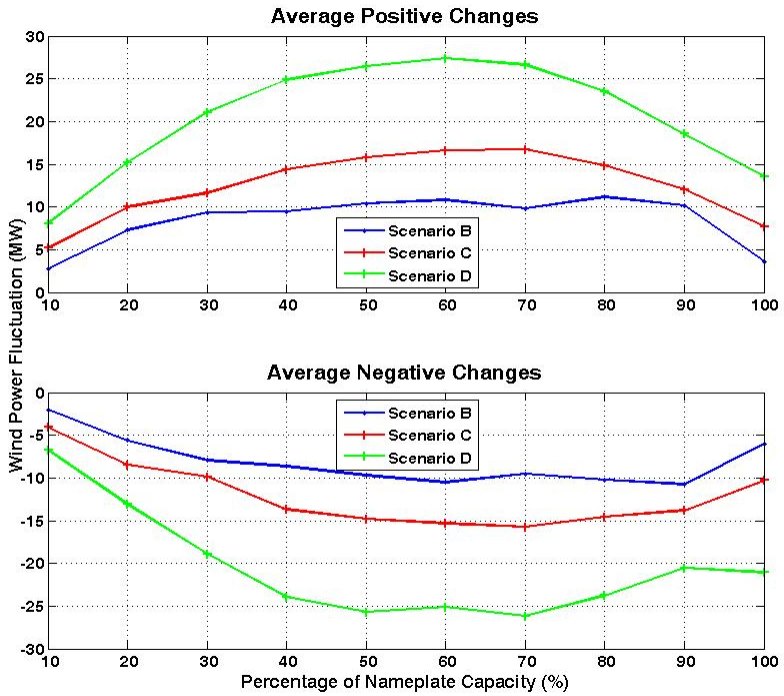
Part 1: Wind Power Variability Analysis

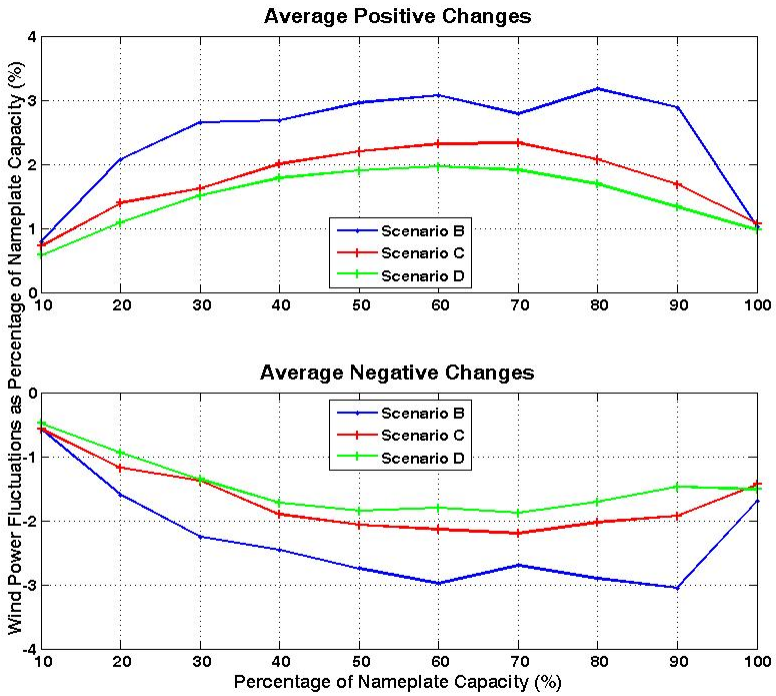
Scenario Description

- Historical: Scenario A (for dispatch model validation only)
- Proposed Future Developments:
  - Scenarios were based on projected on-line dates of projects under development, regardless of locations within the state
  - Scenario B: 358MW, includes Scenario A plus at least 3 new projects
  - Scenario C: 741MW, includes Scenario B plus at least 3 new projects
  - Scenario D: 1450MW, includes Scenario C plus at least 3 new projects
- Hypothetical Developments: Scenario E, Scenario F, Scenario G
  - Designed to capture advantage of regional diversity

Part 1: Wind Power Variability Analysis

- Results: Proposed Scenarios, 10-minute model





Part 1: Wind Power Variability Analysis

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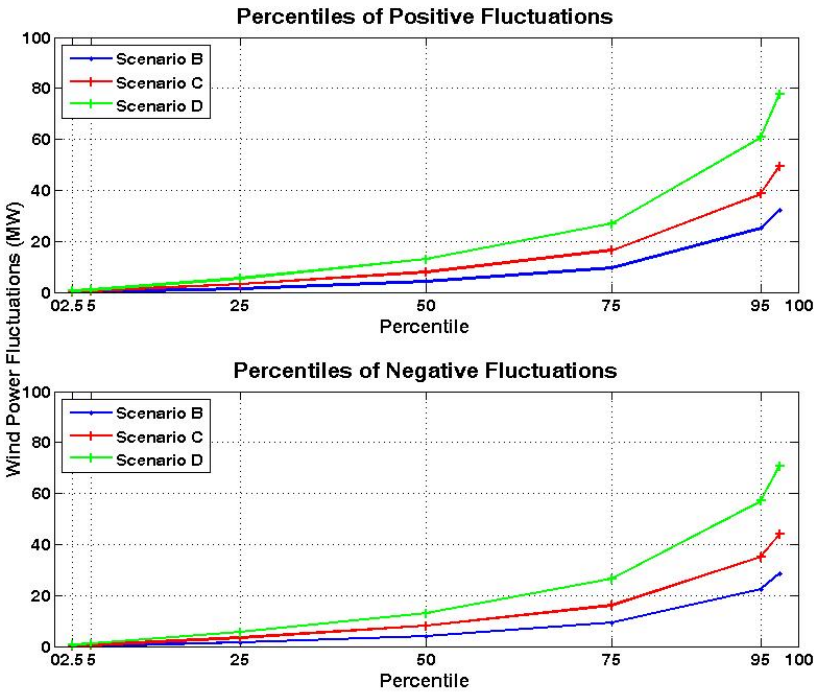
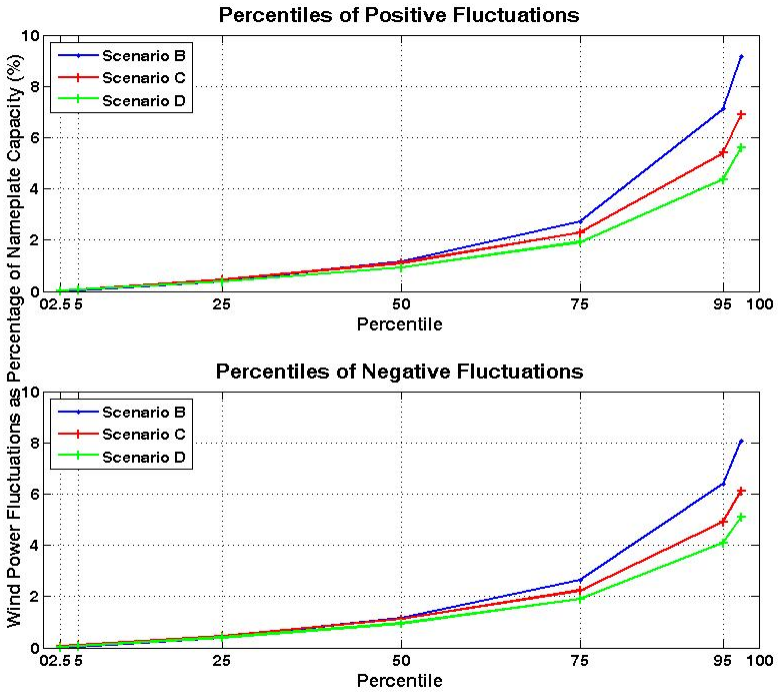
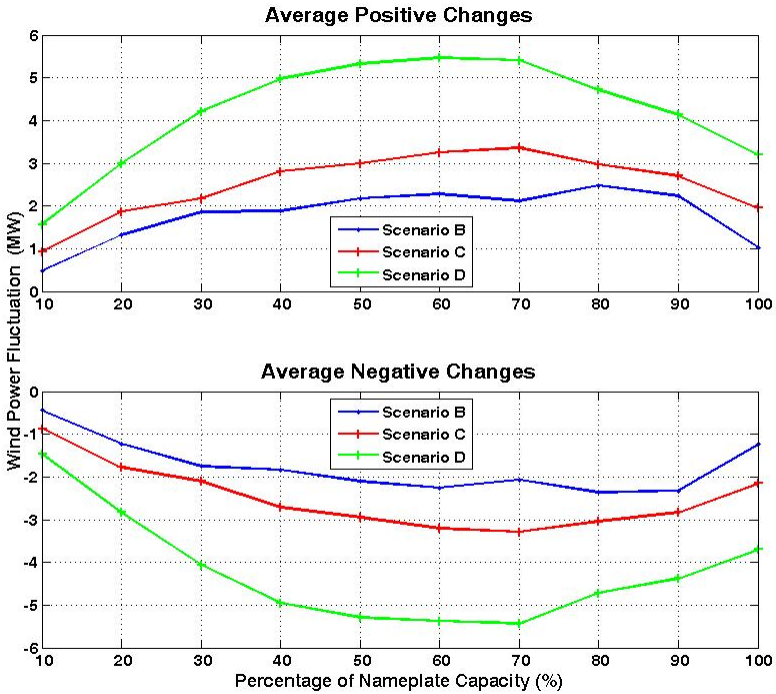
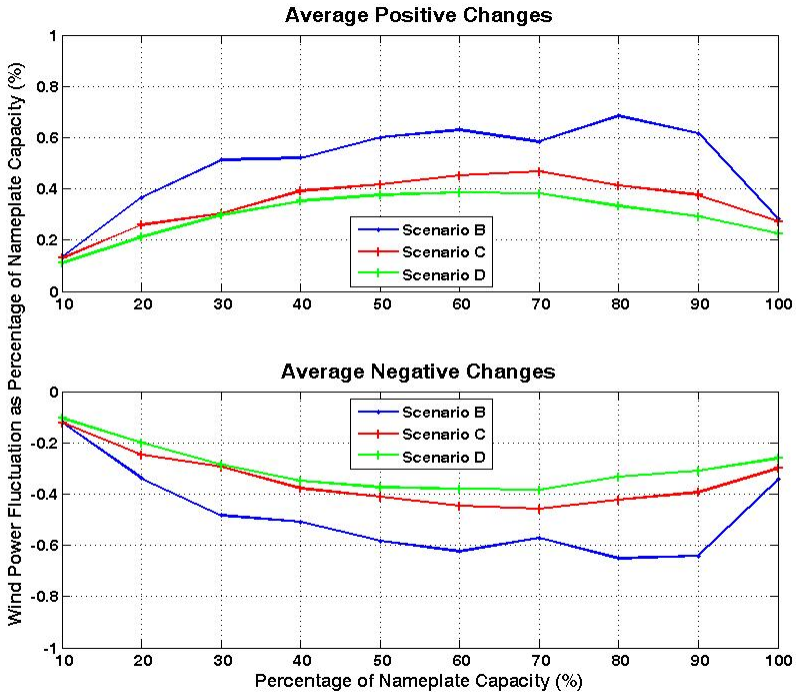




Part 1: Wind Power Variability Analysis

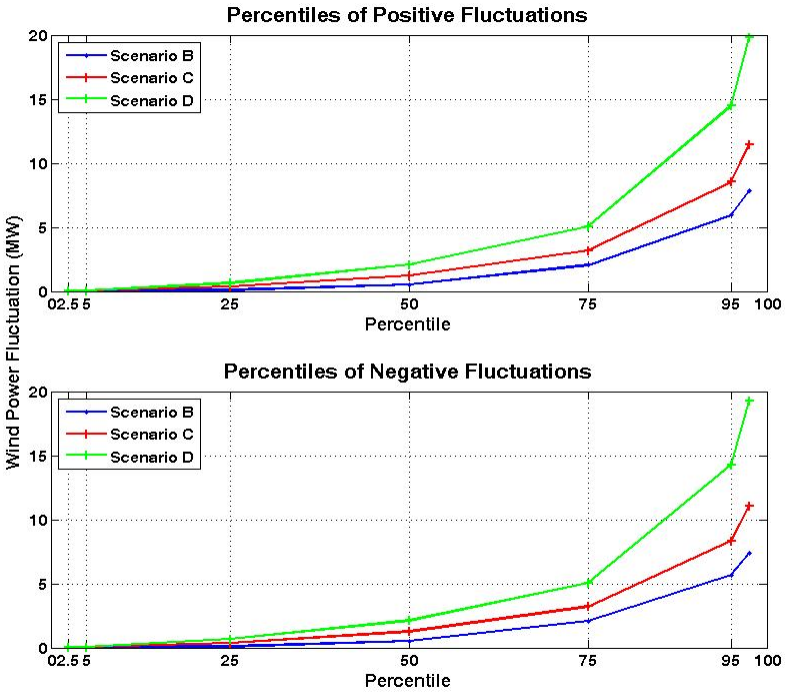
- Results: Proposed Scenarios, 1-minute model

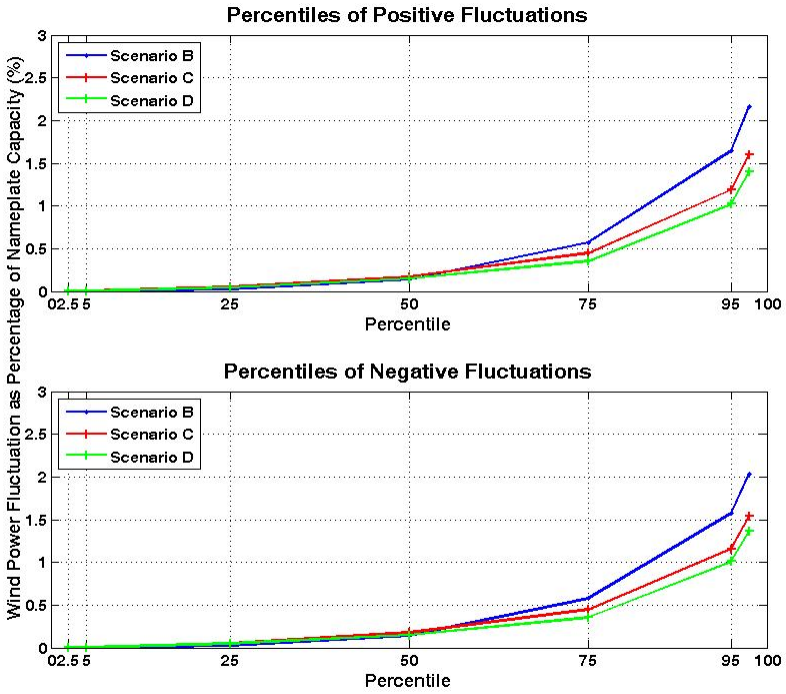




Part 1: Wind Power Variability Analysis

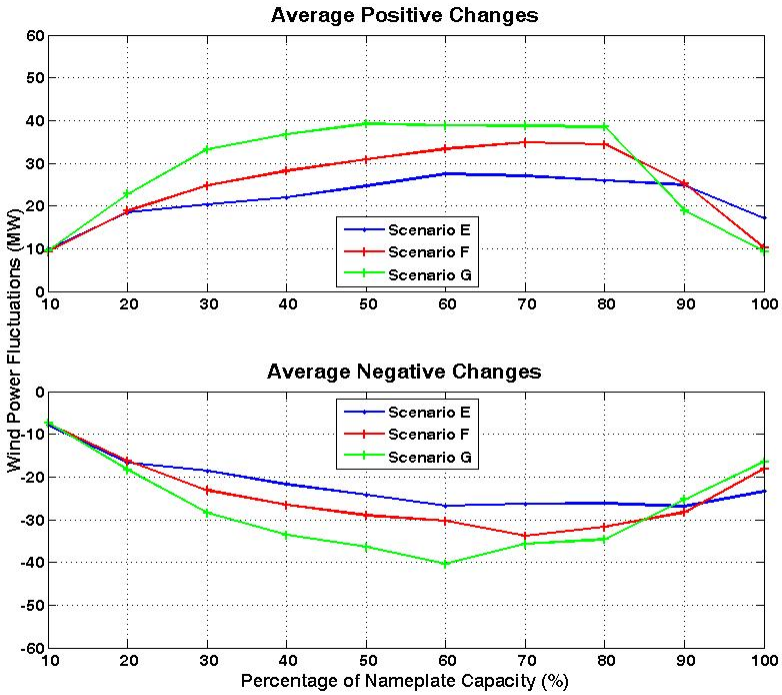
- Results: Proposed Scenarios, 1-minute model

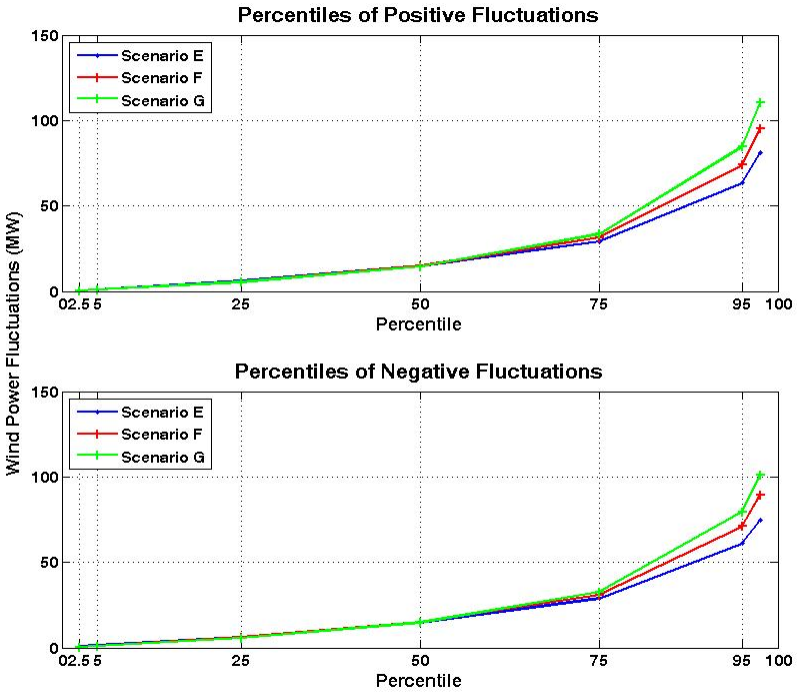




Part 1: Wind Power Variability Analysis

- Results: Hypothetical Scenarios, 10-minute model





Part 2: NWE Dispatch Simulation

- Objective
  - Simulate NWE method of system dispatch
  - Input simulated wind power from Part 1 while maintaining same dispatch methods. Assess impact of additional wind power
  - Evaluate mitigation methods: wind power forecasts and additional regulating reserves
- Significance
  - Guide NWE in planning for new wind power installations
- Challenge
  - Adapting original AESO model to capture NWE system operations

Part 2: NWE Dispatch Simulation

- Model Inputs
  - Simulated Wind Power
  - Historical system load, load forecast, and interchange schedule
  - Operational information: regulating range and rates, conventional generation capacity and rates, etc.

Part 2: NWE Dispatch Simulation

Methodology

- Methodology developed by Alberta Electrical System Operator (AESO)
- Overall simulation approach maintained but specific algorithms were adapted to reflect NWE operations
- Identify benchmark: simulated dispatch with historical wind power data and no forecasting
- Use benchmark for validation with historical dispatch
- Validate by running simulation with historical data and comparing to actual performance

Part 2: NWE Dispatch Simulation

Progress and Plan

- Major required changes from Alberta simulation have been made
- Required system data from Montana has been processed
- The model has been tested with some success, but…
- Benchmark currently does not match historical performance
- Potential causes for the discrepancy have been identified
- Continue modifications and validate performance
- Complete final report and final review with NWE

Conclusion

- Impact of proposed development scenarios to variability
  - Variability in terms of magnitude increases with increased capacity: the 95 percentile value of 10-minute positive fluctuations for Scenario B, Scenario C, and Scenario D are 25.1MW, 38.7MW, and 60.7MW respectively
  - Variability in terms of percentage capacity decreases with increased capacity: the 95 percentile value of 10-minute positive fluctuations for Scenario B, Scenario C, and Scenario D are 7.1%, 5.4%, and 4.4% respectively
- Impact of hypothetical geospatial diversity to variability
  - Variability in terms of magnitude decreases with increased diversity: the 95 percentile value of 10-minute positive fluctuations for Scenario E, Scenario F, and Scenario G are 63.51MW, 73.9MW, and 84.6MW respectively

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Moving Average Wind Speed

$$w_j = \frac{1}{N+1} \sum_{i=j-\frac{N}{2}}^{j+\frac{N}{2}} w_i$$

$$N = T / \Delta t$$

w_j : jth element of the moving average wind speed

w_i : ith element of the original wind speed

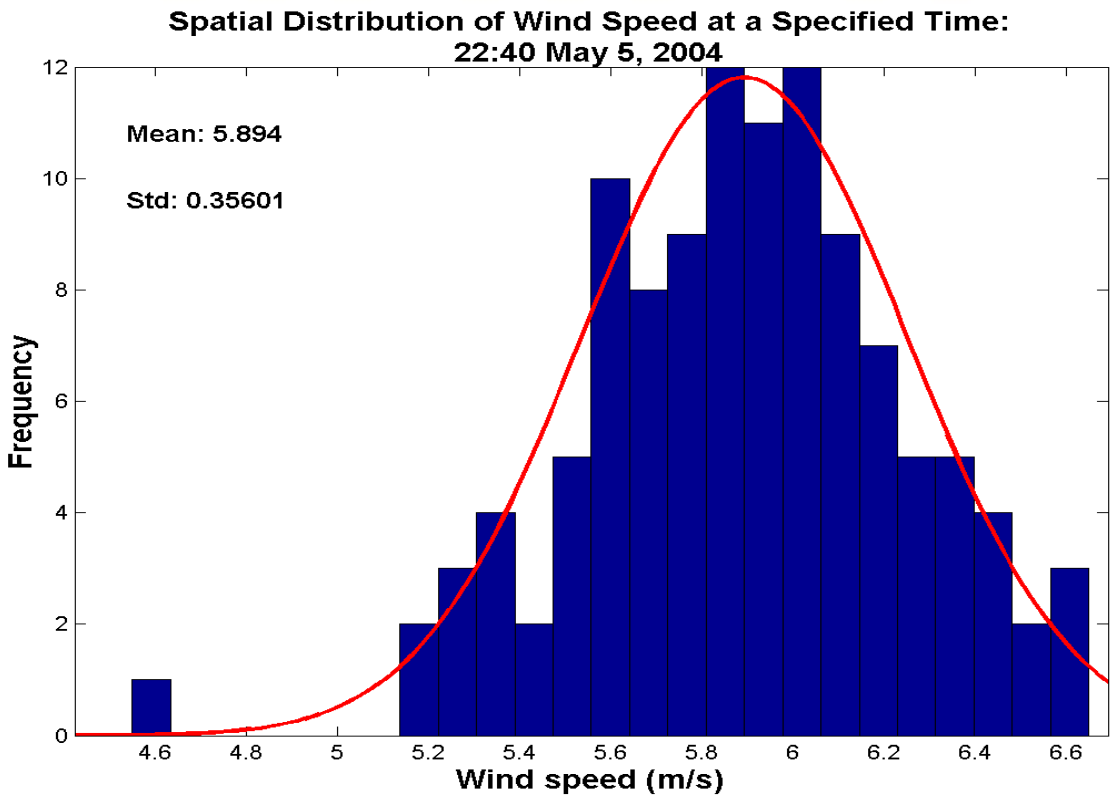
N : the number of points included in each averaging process

T : propagation time

Δt : time step in the original wind speed

Return

Spatial Wind Speed Distribution



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Multi-Turbine Power Curve

$$P_j^m = \sum_i P_{j+i}^s \times p_i^s$$

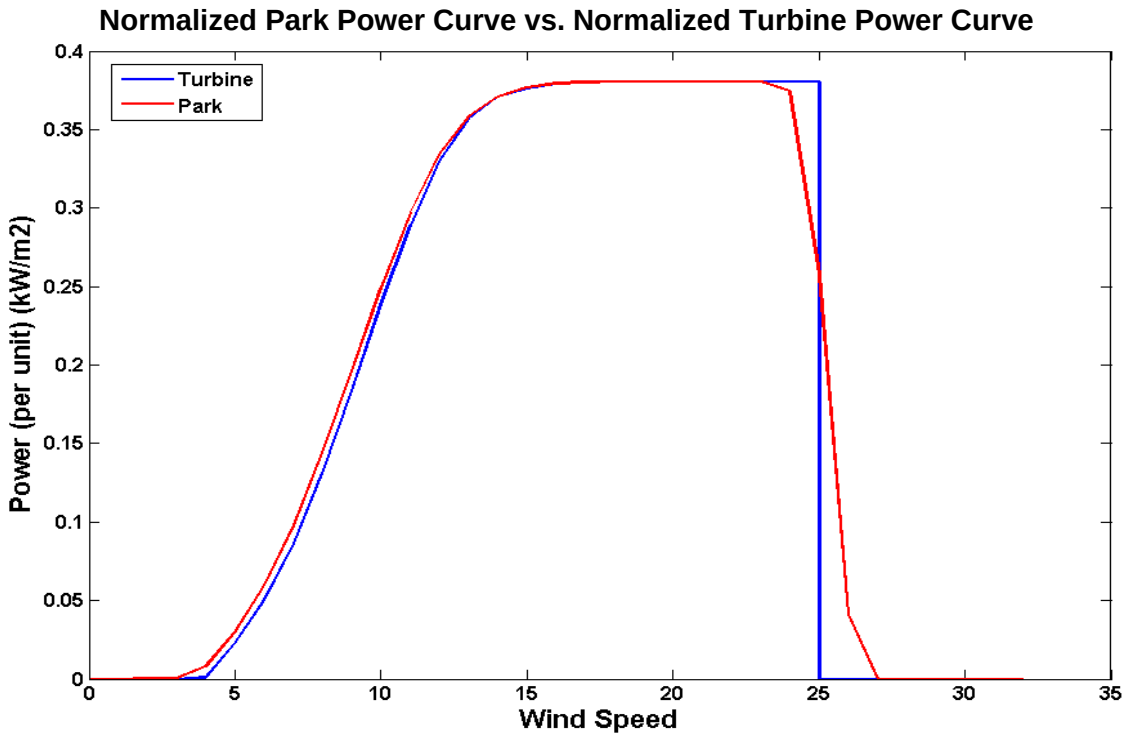
P_j^m : jth element of the multi-turbine power curve

P_{j+i}^s : (j+i)th element of the single-turbine power curve

p_i^s : probability of occurrence of the wind speed corresponding to the normal spatial distribution

Next

Multi-Turbine Power Curve



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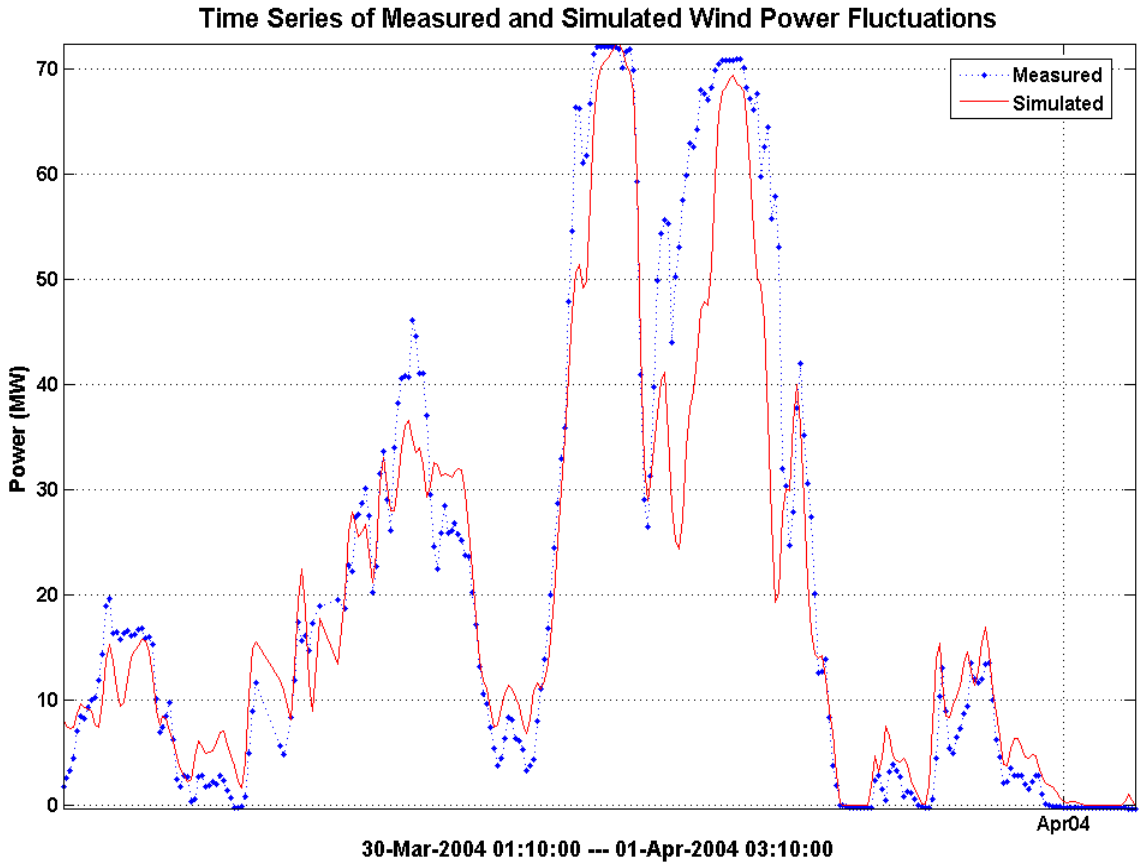
1-Minute Model

- Procedure:
  - Take 10-minute wind power time series
  - Linearly interpolate two successive 10-minute wind power outputs
  - Introduce random perturbations
  - Random perturbations are 10 randomly generated numbers with a normal distribution and specified standard deviation
  - Specified standard deviation is one sixth of the difference between the two successive 10-minute power intervals (empirical value)

Return

Facility Time Series Validation



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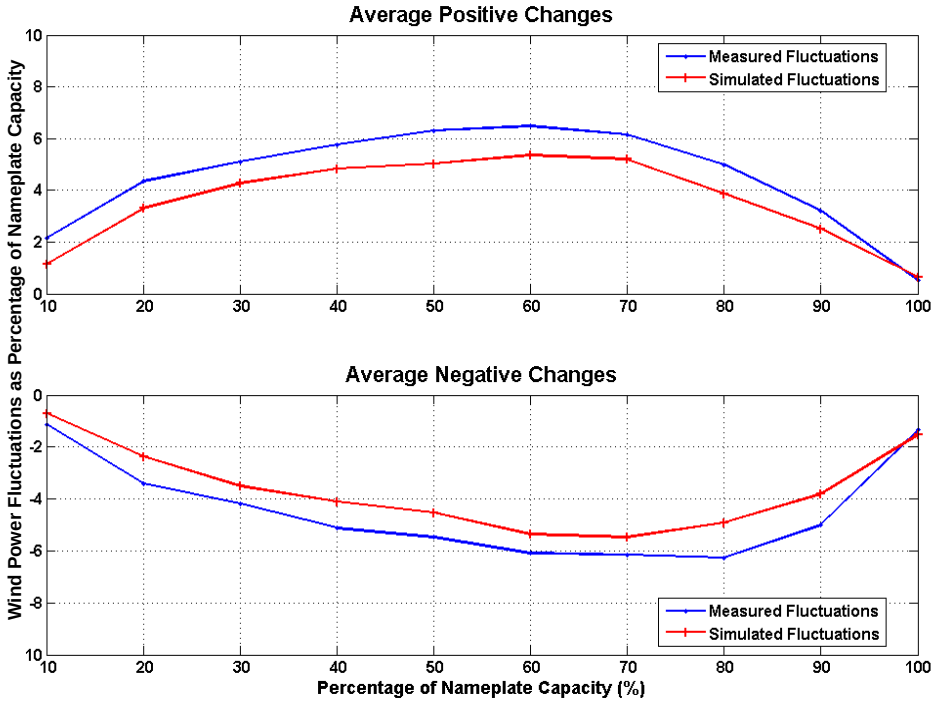
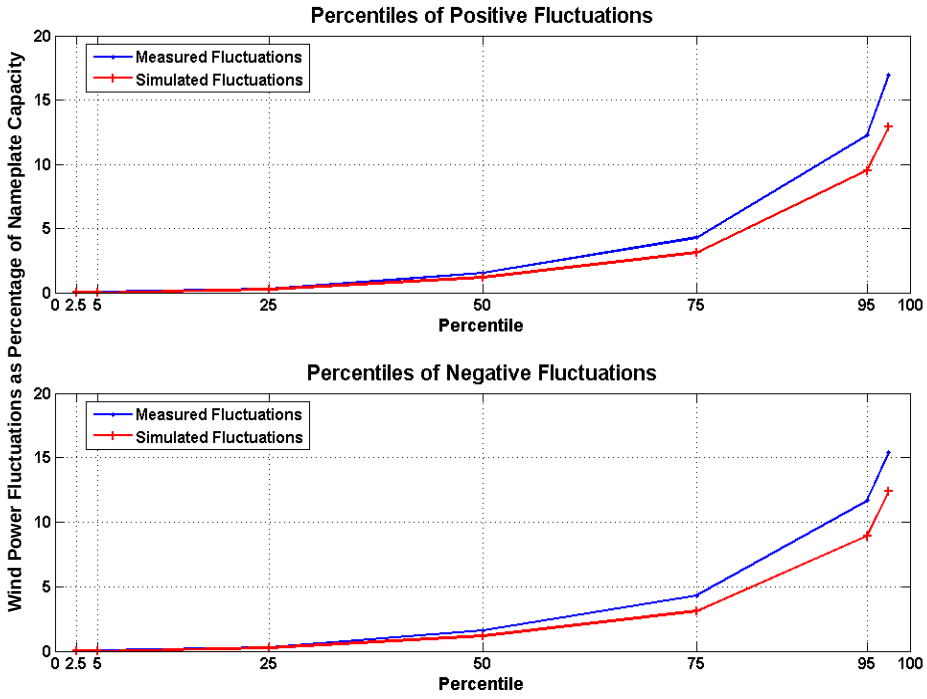
10-Minute Facility Fluctuation Validation





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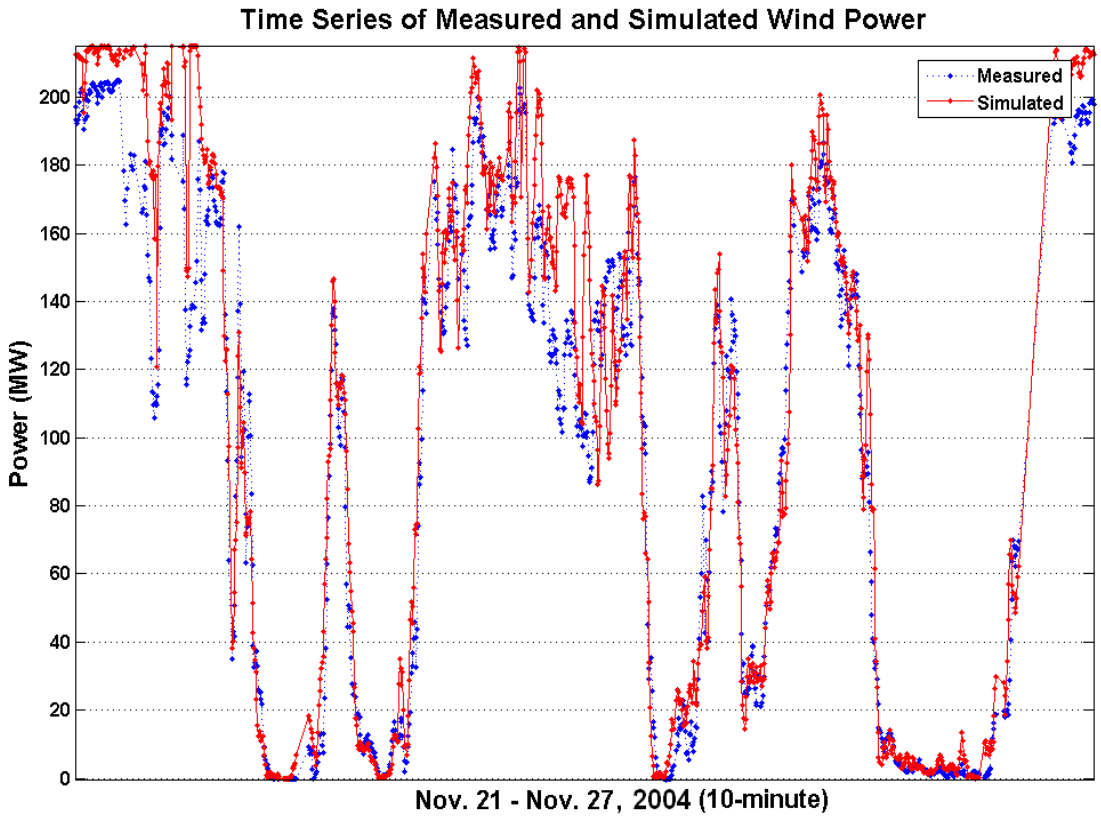
Regional Time Series Validation



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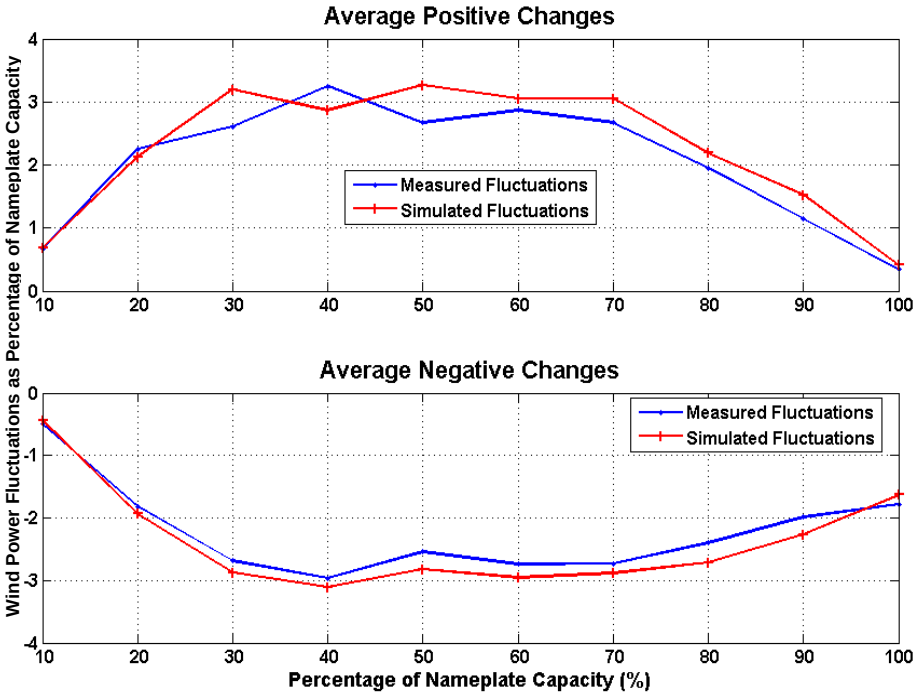
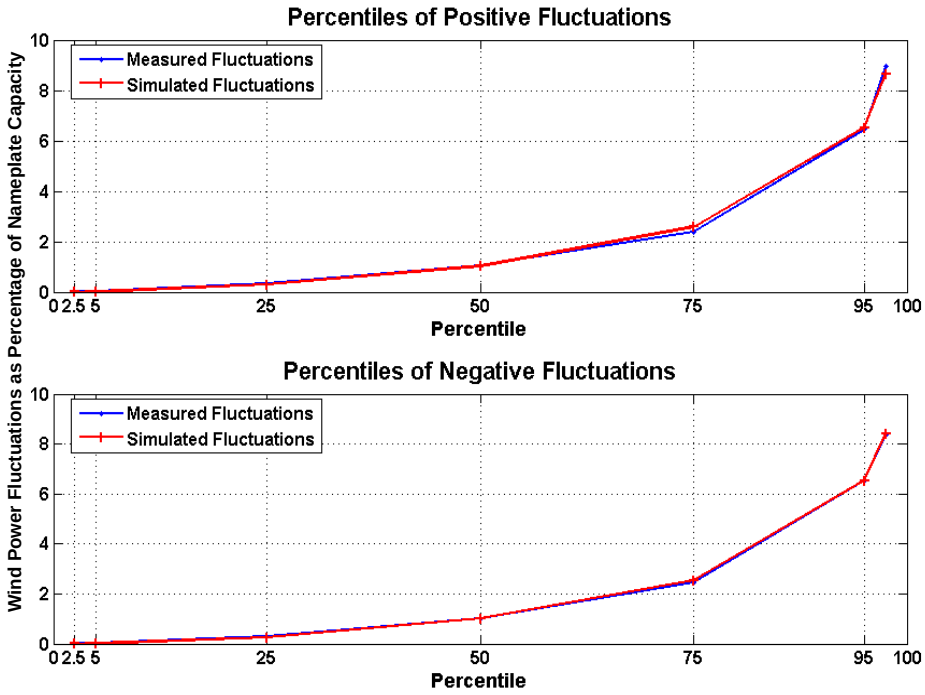
10-Minute Regional Fluctuation Validation





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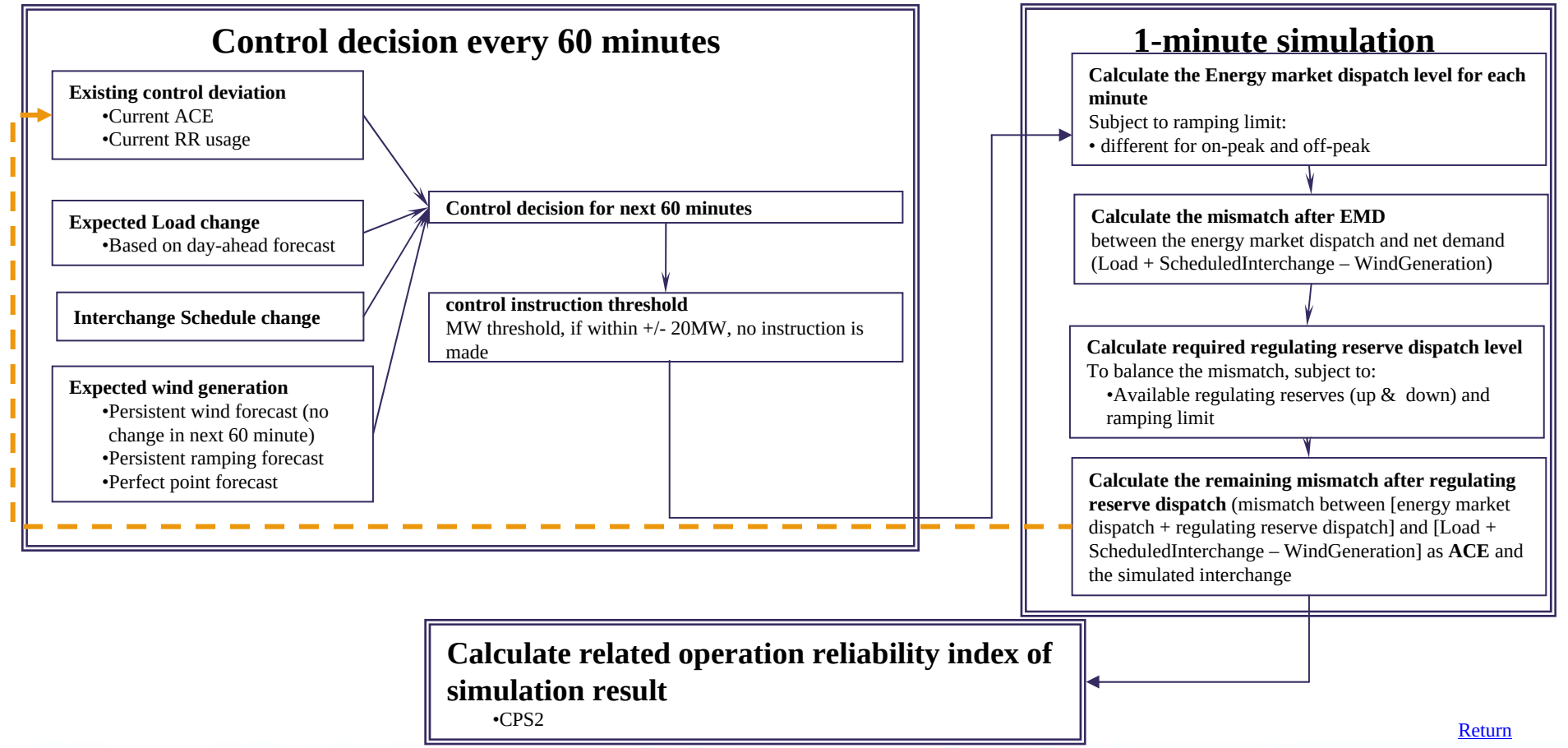
Hypothetical Scenarios

Region	Scenario E	Scenario F	Scenario G
North West	362.5 MW	625 MW	100 MW
Central	362.5 MW	625 MW	1150 MW
South West	362.5 MW	100 MW	100 MW
North East	362.5 MW	100 MW	100 MW
TOTAL	1450 MW	1450 MW	1450 MW

Equivalent capacity to Scenario D

Return

Dispatch Simulation Model



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