Wind Dispatch Using Do-not-Exceed Limit

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BUSINESS ARCHITECTURE AND TECHNOLOGY

Outline

- Motivation
- Current Practice and Issues
- The Proposed Wind Dispatch Process
- DNE Problem and Solution Method
- Numerical Example
- Conclusion

Motivation

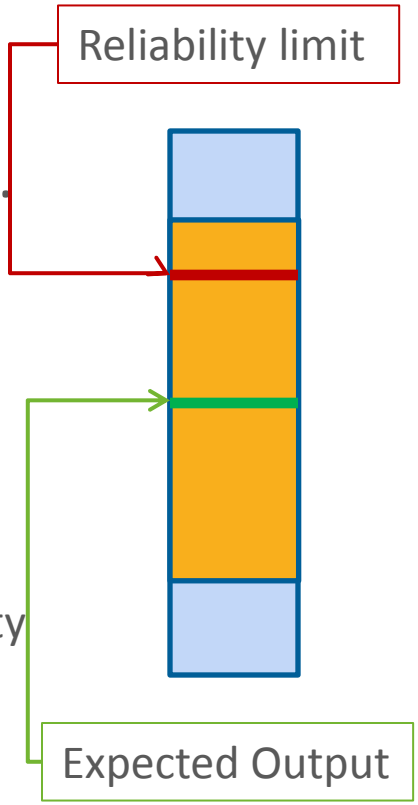
- More wind resources are being integrated into the system operation.
- Different from conventional generators, wind resources are
  - Variable
    - Increased level of uncertainty in the real-time operation
  - Non-dispatchable
    - Wind generation can be only curtailed when reliability issues arise
  - Low operating cost
    - Negative marginal cost
- How do we better utilize the low cost wind resources recognizing their variability?

Existing Real-time Wind Dispatch Practice

- Manual Dispatch
  - Fixed at SCADA values
  - Do not set real-time prices
  - Curtailment through phone calls in the event of transmission violation
  - No enforcement of performance penalty
- Automatic Dispatch
  - Expected output forecasted by the system operator or participants
  - Dispatch between 0 and the expected output
  - Utilize economic offers in the dispatch and pricing
  - Automatic curtailment as long as basepoint < expected output
  - Electronic dispatch with basepoint and/or curtailment flag
  - Allow a wider deviation range when no curtailment is activated

Issues with Existing Practice

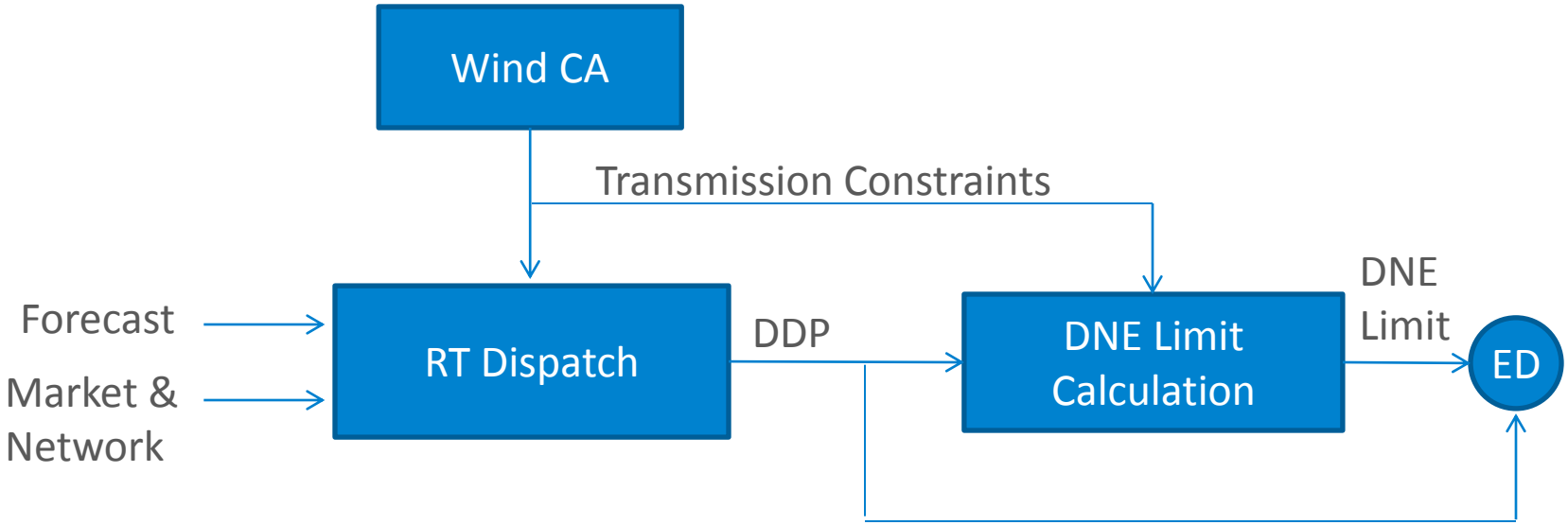
- The dispatch signal does not provide a clear guideline of dispatch following for wind resources.
  - They do not know whether additional wind generation beyond the basepoint will cause any reliability problem.
- The curtailment action is ex post and may not be efficient.
  - Manual Curtailment
    - Is implemented when system already experiencing security problem.
  - Automatic Curtailment
    - Does not differentiate economic-based from reliability-based curtailments



The Proposal: Do not Exceed (DNE) Limit

- Send a do-not-exceed limit to each wind unit
  - Do-not-exceed limit = Reliability limit
- The DNE limit is the maximum amount of wind generation that system can accommodate without causing any reliability issues.
  - Reliability: Capacity and Transmission
  - Uncertainty: Any realization
- Benefits of DNE limit:
  - Provide a dispatch guideline for wind resources
  - Provide incentives for dispatch following
    - Units exceeding their DNE limits are subject to penalty
  - Allow low cost wind resource to provide as much energy as possible

Real-time Wind Dispatch Framework



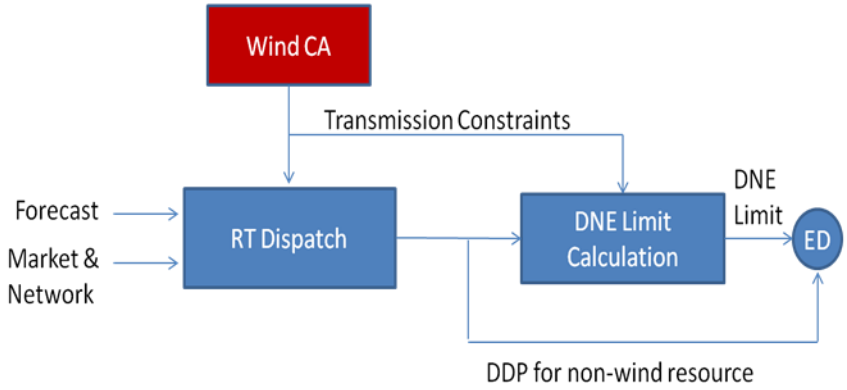
CA – Contingency Analysis

ED - Electronic Dispatch System

DDP – Desired Dispatch Point

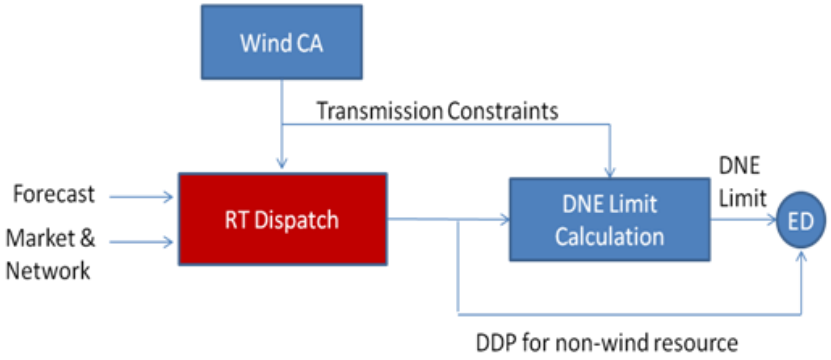
DNE – Do-not-Exceed Limit

Wind CA



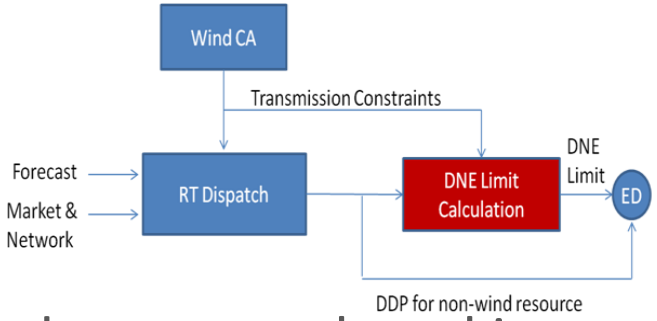
- N-1 Contingency Analysis
  - Loss of line
  - Loss of generator
- Enhancement with wind dispatch
  - Security under expected wind generation
    - Contingency analysis with expected wind output scenario
    - Constraints are generated for the economic dispatch
  - Security under extreme wind realization
    - Zonal basis
    - Loss of wind resource
    - Extreme wind generation
    - Constraints are generated for the DNE limit calculation

Real-time Dispatch



- Market participants submit
  - Real-time high operating limit
  - Generation forecast
  - Meteorology data
  - Outage information
- ISO forecasts the expected output of each wind resource.
- In the dispatch, each wind unit is
  - Dispatchable (allowed for price setting)
  - Dispatched between 0 and its expected output level
  - Dispatched against its energy offer

DNE Limit Calculation



- Produce the reliability limit for each wind resources by taking account system control actions.
- DNE Limit Problem Formulation
  - An optimization problem to find the minimum and maximum output level of a wind resource while satisfying the following conditions:
    - System is able to maintain energy balance under any output variation of wind resources by adopting a set of control actions,
    - The flow on any transmission line remains within its limit under any realization of uncertain output level of wind resources,
    - The corrective control action must be subject to its corresponding physical limits,
    - The output variation of a wind resource should be within its physical limits.

Not a Standard Robust Optimization Problem

- A standard two-stage robust optimization problem:

$$\min_{x,\,p(\bullet)} \left(c^T x + \max_{w \in [w^{LB}, w^{UB}]} g(p(w)) \right)$$

$$\text{s.t.} \quad Ax + Bp(w) + Dw \le h, \forall w \in [w^{LB}, w^{UB}]$$

$$x \in X$$

  - Determine the best control decision *x* to accommodate the worst case
  - The uncertainty set is pre-defined

- DNE limit problem:

$$\min_{p(\bullet), w^{LB}, w^{UB}} f(w^{LB}, w^{UB})$$

$$\text{s.t.} \quad Ax^* + Bp(w) + Dw \le h, \forall w \in [w^{LB}, w^{UB}]$$

$$(w^{LB}, w^{UB}) \in \mathcal{W}$$

  - Determine the largest uncertainty range that a system can accommodate
  - The uncertainty set is to be determined

Solution Strategies

- The DNE Limit problem can be considered as a reverse of an adaptive robust optimization problem, which is difficult to solve in general.
- Approximation can be made to the adaptive/corrective actions to reduce the complexity of the solution method.
- Three approximation strategies
  - Affine policy with fixed participation factor
  - Affine policy with optimal participation factor
  - Fully adaptive strategy

Affine Policy

- Assume that the output of a corrective action unit changes linearly with respect to the uncertainty realization

$$p_j(w) = p_j^* + E_j \cdot \left(w - w^*\right)$$

Participation vector

- Substitution and Dualize the robust constraint

$$\min_{p(\bullet), w^{LB}, w^{UB}} f(w^{LB}, w^{UB})$$
$$\text{s.t.} \quad Ax^* + Bp(w) + Dw \le h, \forall w \in [w^{LB}, w^{UB}]$$
$$(w^{LB}, w^{UB}) \in \mathcal{W}$$

$$\min_{w^{LB}, w^{UB}, E, \alpha} f(w^{LB}, w^{UB})$$
$$\text{s.t.} \quad \left(Ax^* + Bp^* - BEw^*\right) + \alpha^{+T} w^{UB} - \alpha^{-T} w^{LB} \le h$$
$$\alpha^+ - \alpha^- = \left(D - BE\right)^T$$
$$(w^{LB}, w^{UB}) \in \mathcal{W}$$

Affine Policy

- Affine policy with fixed participation factors
  - The participation vector E can be fixed based on engineering experience.
  - α^{-} *and* α^{+} can be predetermined

$$\left\{\alpha^{-}\right\}_{j,k} = \min(\left(D - BE\right)_{j,k}, 0) \qquad \left\{\alpha^{+}\right\}_{j,k} = \max(\left(D - BE\right)_{j,k}, 0)$$

  - The corresponding problem is an LP problem
- Affine policy with optimal participation factors
  - Paticipation vector E is a decision variable
  - α^{-} *and* α^{+} are variables too
  - DNE problem is a bilinear problem

Fully Adaptive Strategy

- For any w_k in the interval $[w_k^{LB}, w_k^{UB}]$, it can be expressed as follows:

$$w_k = z_k w_k^{LB} + (1 - z_k) w_k^{UB}, \forall z_k \in [0,1]$$

- Reformulation : two-stage adaptive robust optimization problem

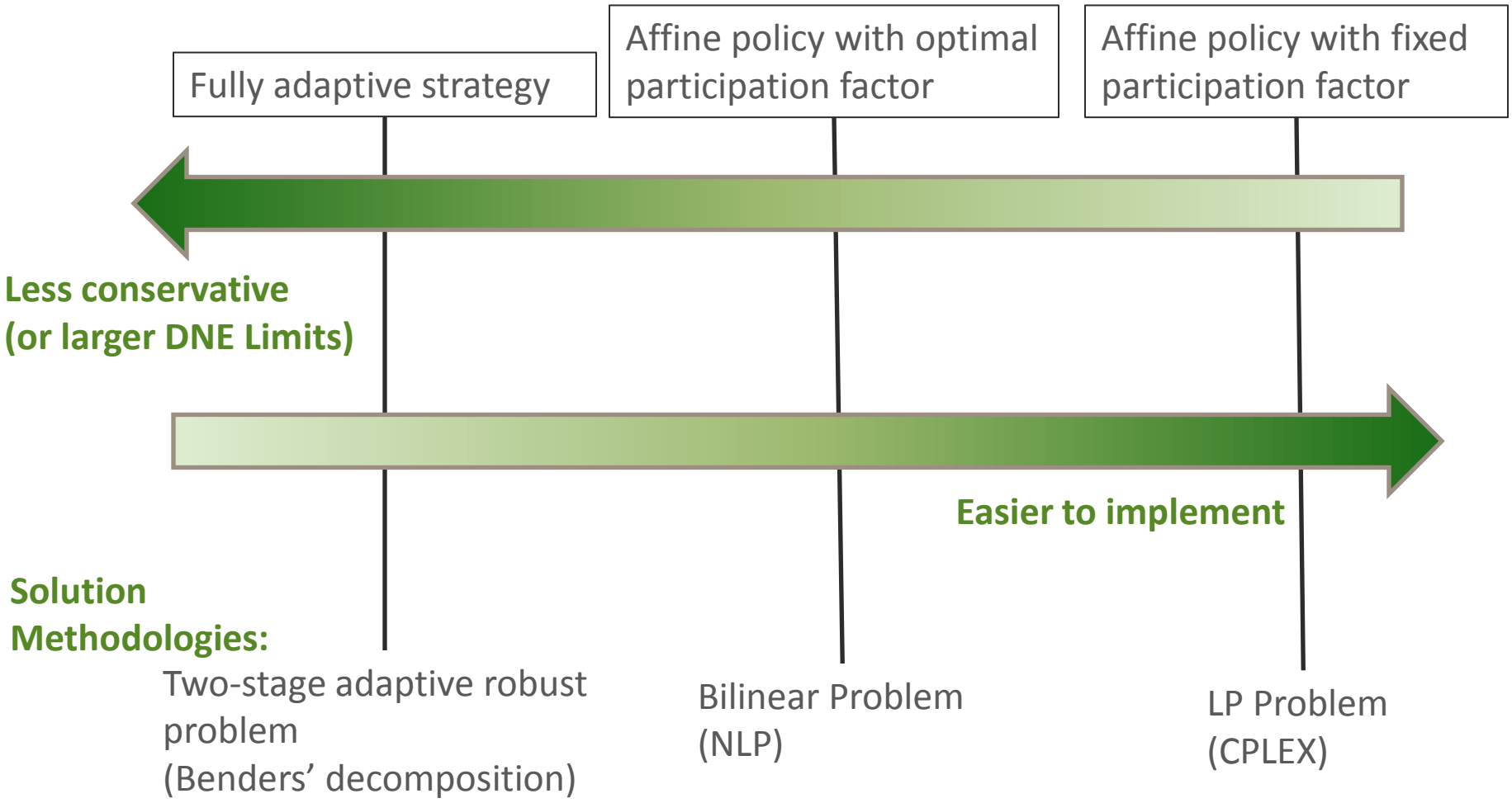
$$\min_{p(\bullet), w^{LB}, w^{UB}} f(w^{LB}, w^{UB})$$
$$\text{s.t.} \quad Ax^* + Bp(w) + Dw \le h, \forall w \in [w^{LB}, w^{UB}]$$
$$(w^{LB}, w^{UB}) \in \mathcal{W}$$

+

$$w = Zw^{LB} + (I - Z)w^{UB}, Z \in [0, I]$$

$$\min_{p(\bullet), w^{LB}, w^{UB}} f(w^{LB}, w^{UB})$$
$$\text{s.t.} \quad Ax^* + Bp(z) + DZw^{LB} + D(I - Z)w^{UB} \le h, \forall Z \in [0, I]$$
$$(w^{LB}, w^{UB}) \in \mathcal{W}$$

Comparison of Three Solution Strategies



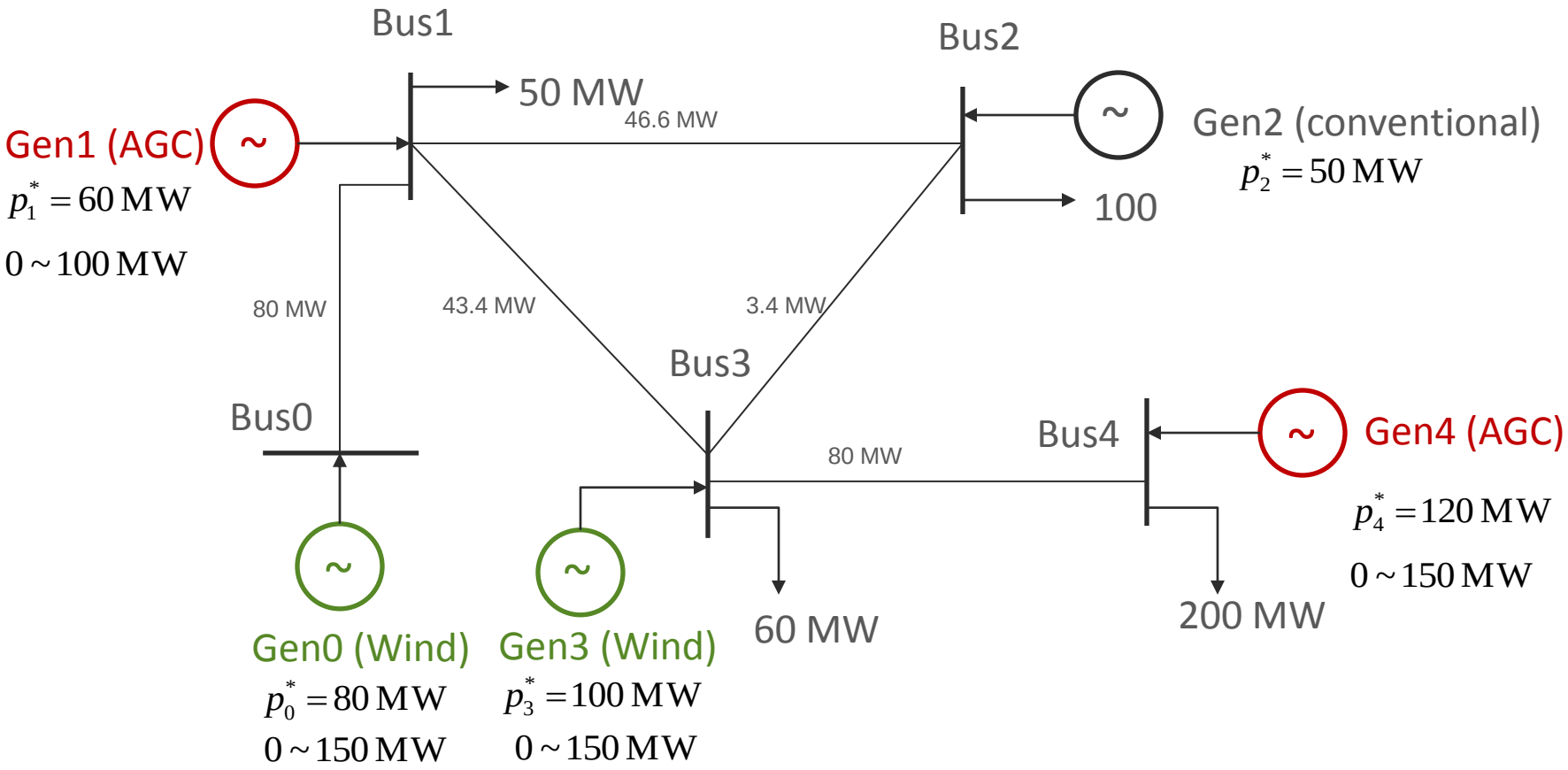
5-Bus Examples

- Generator Information

Resources	Type	Location	Bid ($/MWh)	Dispatch Min (MW)	Dispatch Max (MW)	Physical Min (MW)	Physical Max (MW)
Gen0	Wind	Bus0	0	0	80	0	150
Gen1	AGC	Bus1	10	40	100	0	100
Gen2	Conventional	Bus2	15	50	100		
Gen3	Wind	Bus3	0	0	100	0	150
Gen4	AGC	Bus4	20	120	150	0	150
Load1	Fixed	Bus1		50	50		
Load2	Fixed	Bus2		100	100		
Load3	Fixed	Bus3		60	60		
Load4	Fixed	Bus4		200	200		

- Only AGC units are assumed to perform corrective control in the example.

5-Bus Example: Dispatch Solution



Transmission flow limit for each line is 100 MW.

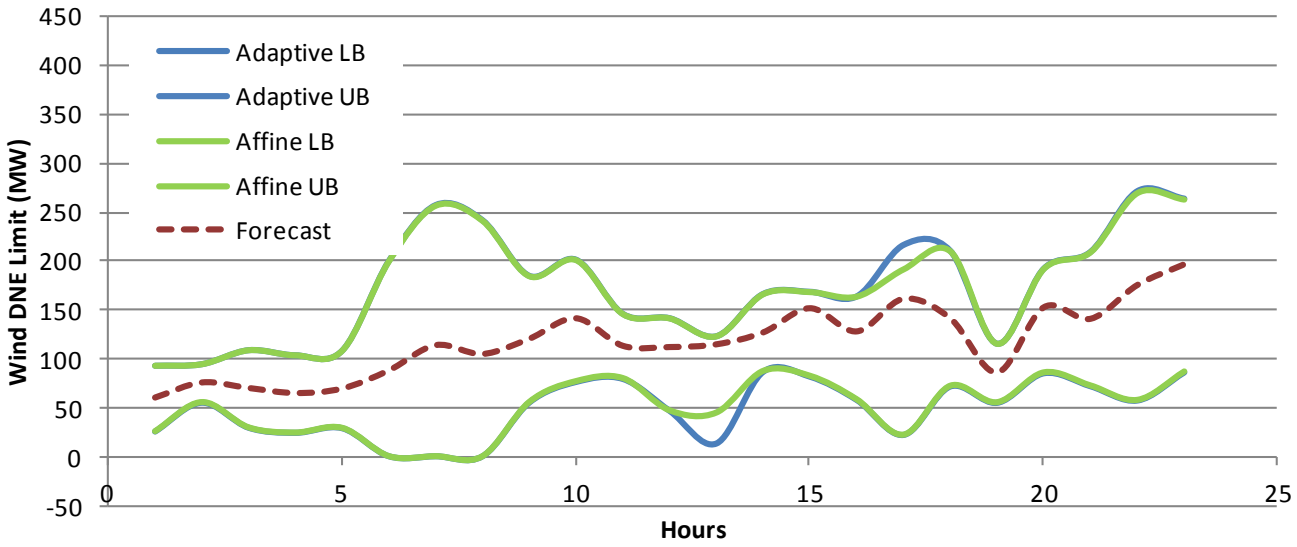
5-Bus Example: DNE Limits

Approaches	Gen0 (DNE Limit)	Gen1 (e)	Gen2 (DDP)	Gen3 (DNE Limit)	Gen4 (e)	Total Range of DNE Limit
Affine (fixed e)	[58.3~100]	0.4	50 MW	[71.7~113.3]	0.6	83.3 MW
Affine (optimal e)	[24~100]	0.714	50 MW	[100~150]	0.286	126 MW
Fully adaptive	[80~100]	N/A	50 MW	[30~150]	N/A	140 MW

- Fully adaptive approach results in the largest total DNE limit range
- Affine policy approach with fixed participation factor results in the smallest total DNE limit range
- The fixed participation factor can be very different from the optimal counterpart.

ISO New England System Example

- Jun 1st , 2011 Data
  - 6 wind generators with total capacity of 250 MW
  - 1~3 AGC units with regulation capability of 20~140 MW



- Two affine approaches yield the same results
- The advantage of the adaptive approach is not significant

Conclusion

- A wind dispatch framework using the DNE limit is proposed.
- The proposed dispatch framework
  - Provides a more clear dispatch guideline for wind resources
  - Provides better incentives for dispatch following
  - Accommodates more low cost wind generation
- A systematic way of determining the DNE limits for wind power resources is proposed based on the robust optimization technique.
- Three solution strategies are investigated.
  - The fixed participation factor affine policy approach is more suitable for the real-time operation.

Questions