LMPs in electricity markets: The case for simple bids

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Presentation at FERC Conference on Increased Market and Planning Efficiency, Docket No. AD10-12-005

06/24/2014 Washington DC

Outline

- Introduction
  - Uncertainties in real-time power balancing
  - Problem of power imbalance created by new uncertainties (non-complying generators)
- Proposed Framework for Real-Time Dispatch under Uncertainty
  - Predictor – Robust Scheduler – Enhanced AGC for real-time power balancing
- Proposed Market Structure
  - Market clearing and settlement process
  - LMP calculation based on simple bids
- Impact of Uncertainty and Risk Preference on LMPs
- Conclusion

Uncertainties in Real-Time Power Balancing

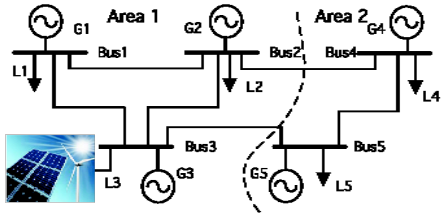
In Traditional Industry

- Generation Uncertainty
  - Due to physical limitation of generators, such as governors, etc.
- Demand Uncertainty
  - Hard to predict real time demand

In New Industry

- Generation uncertainty
  - Gaming in deregulated market
- Demand uncertainty
  - Consumer's behavior is stochastic in demand response scenario
- Uncertainty of intermittent resources
  - Large variations, hard to predict

5-Bus Test System with Generator Uncertainties



"Slow" Generators

"Fast" Generators

Generator	Marginal Cost ($/p.u.)	Minimum Generation (p.u.)	Maximum Generation (p.u.)	Region of Deviation Ω (% of committed)
1	80	0	0.4	−30% ~ −10%
2	88	0	0.5	−20% ~ −10%
3	100	0	0.5	−5% ~ +5%
4	258	0.18	0.4	0
5	261	0.18	0.4	0

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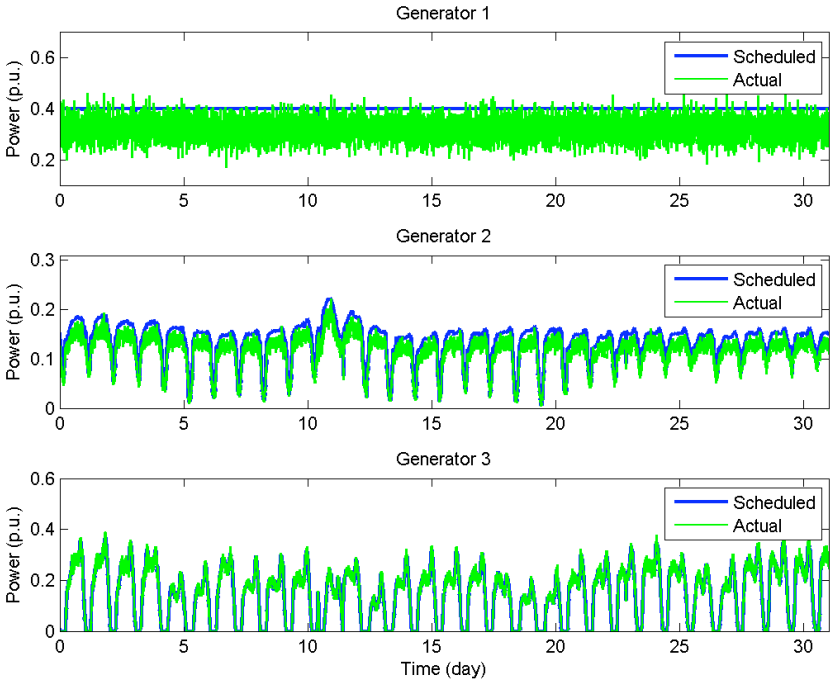
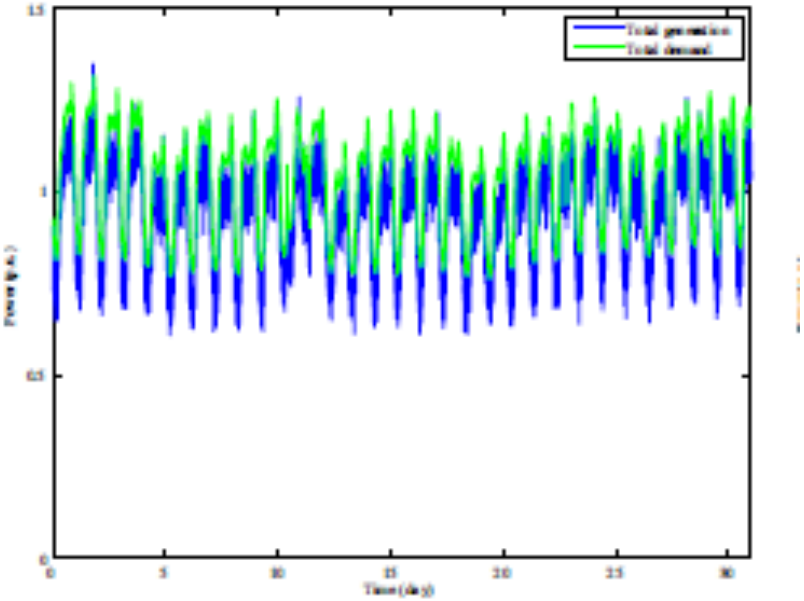
Imbalances Created by Generator Deviations

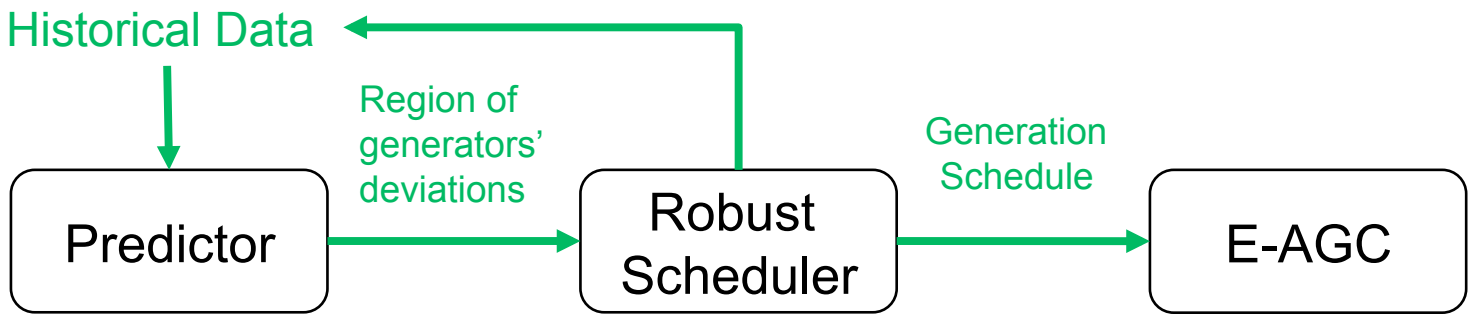
- Conventional economic dispatch fails to balance supply and demand
- Need to utilize more expensive resources in real time (AGC)





Non-zero mean imbalance

Proposed Framework for Uncertainty Management



- Predict the region of generators' deviation using historical data
- Conduct real-time economic dispatch, taking cost to recover from deviations into account
- Compensate imbalances left in real time

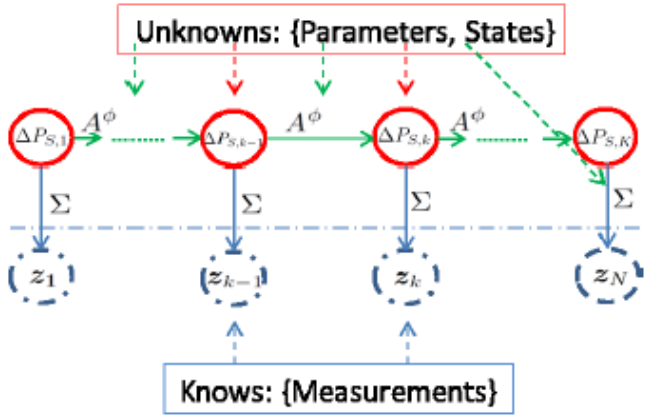
Generator Deviation Predictor

- Modeling deviation dynamics
  - $P_{S,k}$: scheduled generation of slow generators at time step k
  - $\widetilde{P_{S,k}}$: measured actual generation; $\Delta P_{S,k}$: deviation
  - Assume linear dynamics of deviations $\Delta P_{S,k}$

$$\Delta P_{S,k} = A\Delta P_{S,k-1}$$

$$z_k = \tilde{P}_{S,k} - P_{S,k} = \Delta P_{S,k} + W_k$$

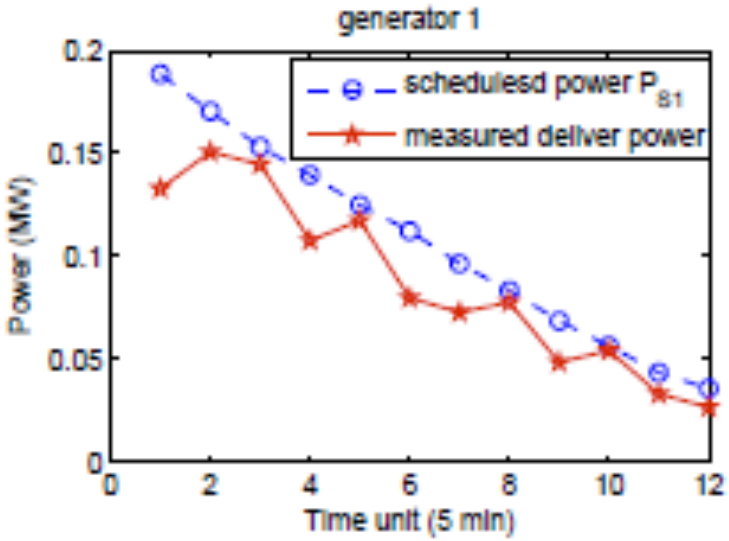
$$W_i \sim \mathcal{N}(0, \sigma_i)$$

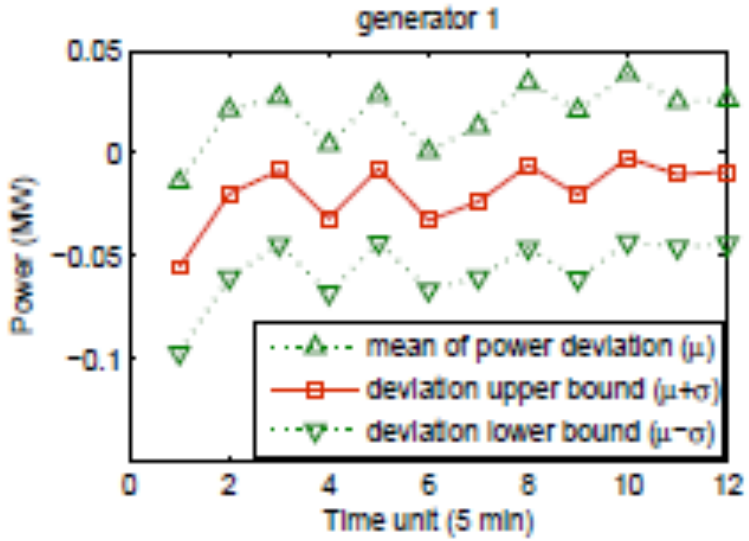


- Estimate parameters A, Σ
  - Expectation-Maximization
- Objective: estimate region of deviation $\widehat{\Omega}$ for all generators

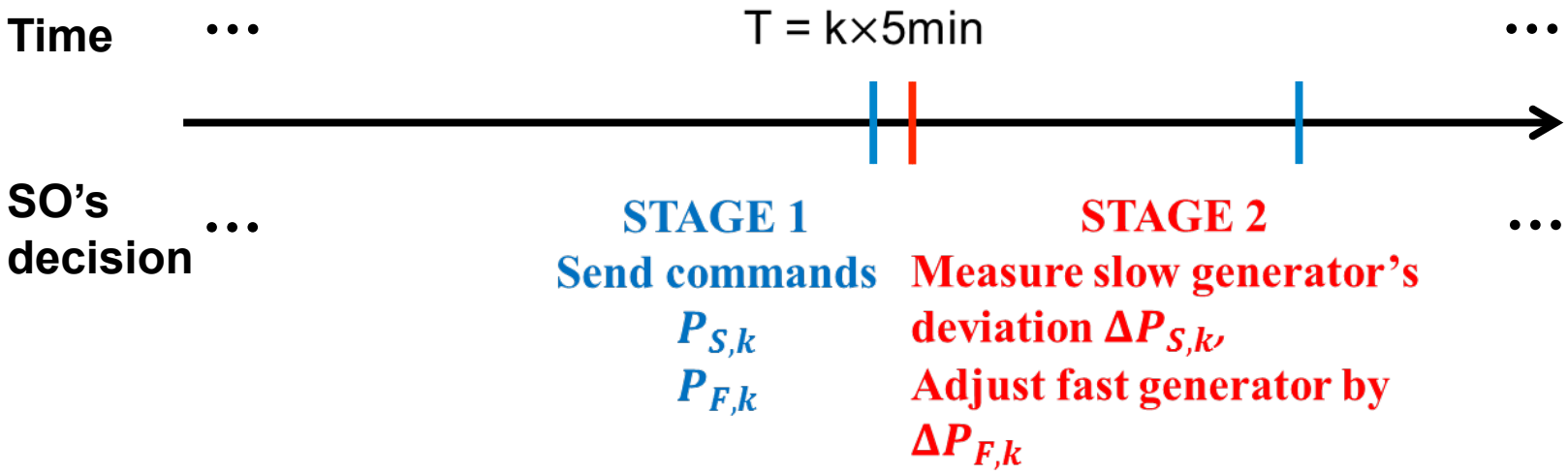
Generator Deviation Predictor

- Simulation Results





Robust Scheduler: Recovery Cost



- Recovery cost: $R(P_S, P_F, \Delta P_S)$--- cost incurred by adjusting fast generators in Stage 2

$$R(P_S, P_F, \Delta P_S) = \min_{\Delta P_F \in \Omega(P_S, P_F, \Delta P_S)} \Delta P_F^T Q \Delta P_F,$$

where, $\Omega(P_S, P_F, \Delta P_S) = \{\Delta P_F \in \mathbb{R}^{n_F} |$

$$\sum_{i=1}^{n_S} (P_{Si} + \Delta P_{Si}) + \sum_{i=1}^{n_F} (P_{Fi} + \Delta P_{Fi}) = \sum_{i=1}^{n_D} P_{Di}$$

$$|F(P_S, P_F, \Delta P_S, \Delta P_F)| \leq F^{max} \}$$

Q controls the difficulty of recovery

Robust Real-Time Economic Dispatch

- Worst-case recovery cost $R_{wc}(P_S, P_F; \hat{\Omega})$:recovery cost caused by most severe deviation ΔP_S

$$R_{wc}(P_S, P_F; \hat{\Omega}) = \max_{\Delta P_S \in \hat{\Omega}} R(P_S, P_F, \Delta P_S)$$

- Robust economic dispatch considering worst-case recovery cost

Stage-1 Cost

Worst-Case Recovery Cost

Output: Scheduled generation

$$\min_{P_S, P_F} \; C_S(P_S) + C_F(P_F) + R_{wc}(P_S, P_F; \hat{\Omega})$$

$$s.t. \quad \sum_{i=1}^{n_S} P_{Si} + \sum_{i=1}^{n_F} P_{Fi} = \sum_{i=1}^{n_D} P_{Di}, \qquad \text{Supply-demand balance}$$

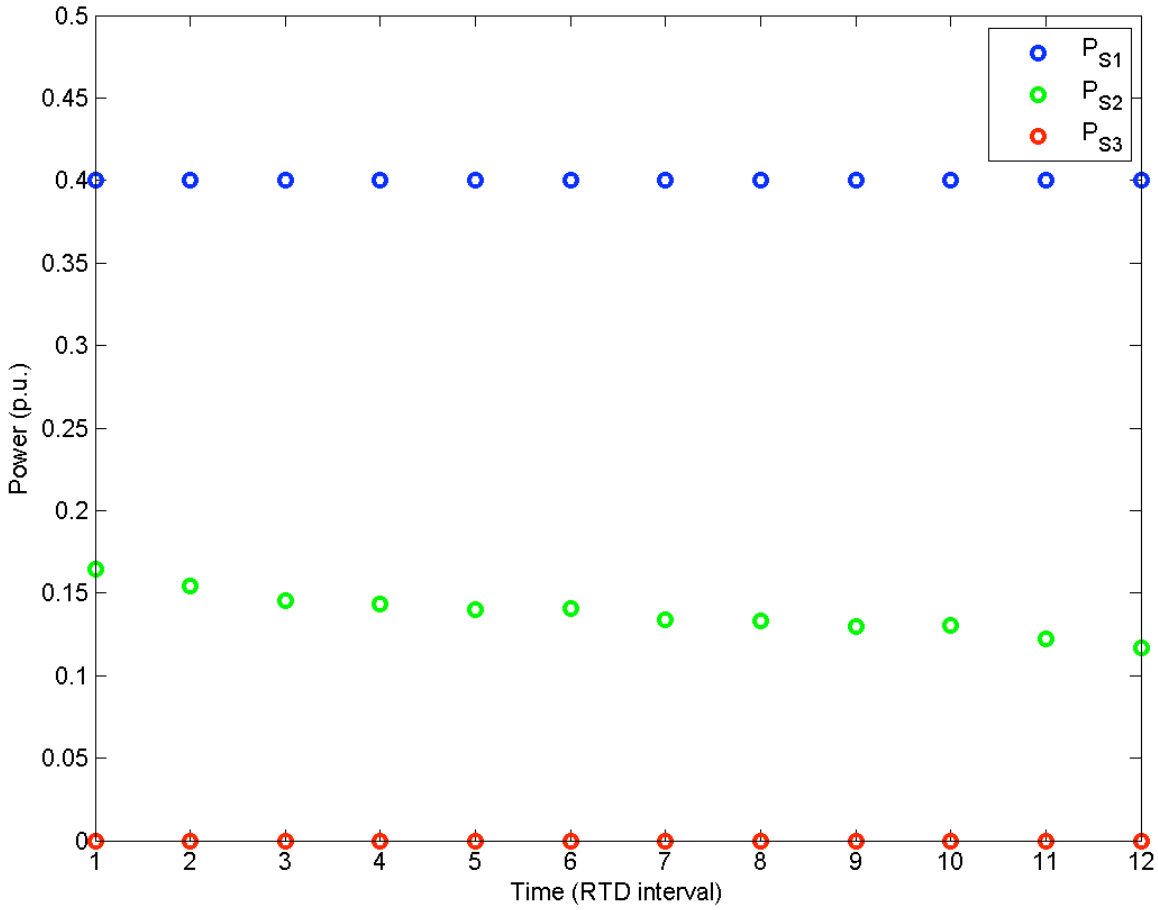
$$|F(P_S, P_F)| \le F^{max}, \qquad \text{Flow limits constraints}$$

$$P_S^{min} \le P_S \le P_S^{max}, \; P_F^{min} \le P_F \le P_F^{max} \qquad \text{Generation limits}$$

Simulation Results

- Conventional economic dispatch (Q = 0)

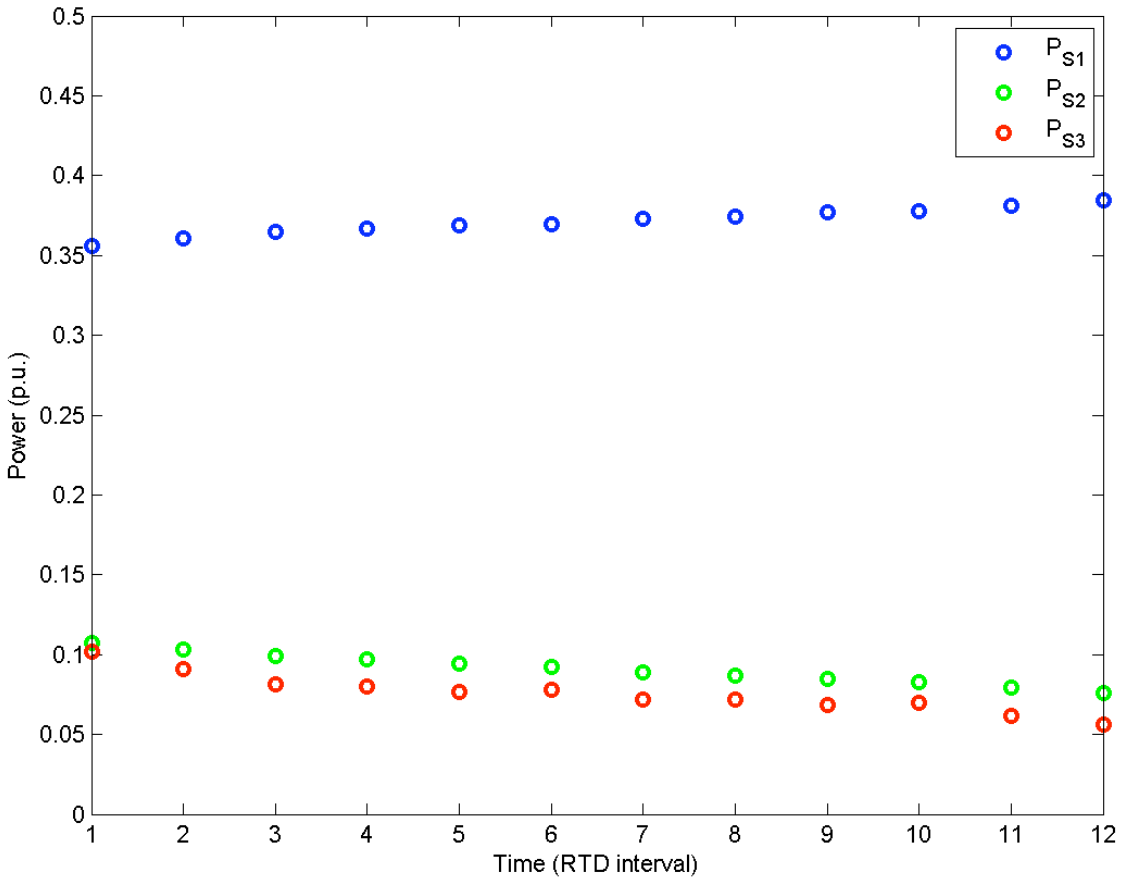
ID	Cost	Actual Generation
1	80	70%-90% of committed
2	88	80%-90% of committed
3	100	95%-105% of committed



Simulation Results

- Robust economic dispatch (Q = 600× I)

ID	Cost	Actual Generation
1	80	70%-90% of committed
2	88	80%-90% of committed
3	100	95%-105% of committed



Simulation Results

- Robust economic dispatch (Q = 2500× I)

ID	Cost	Actual Generation
1	80	70%-90% of committed
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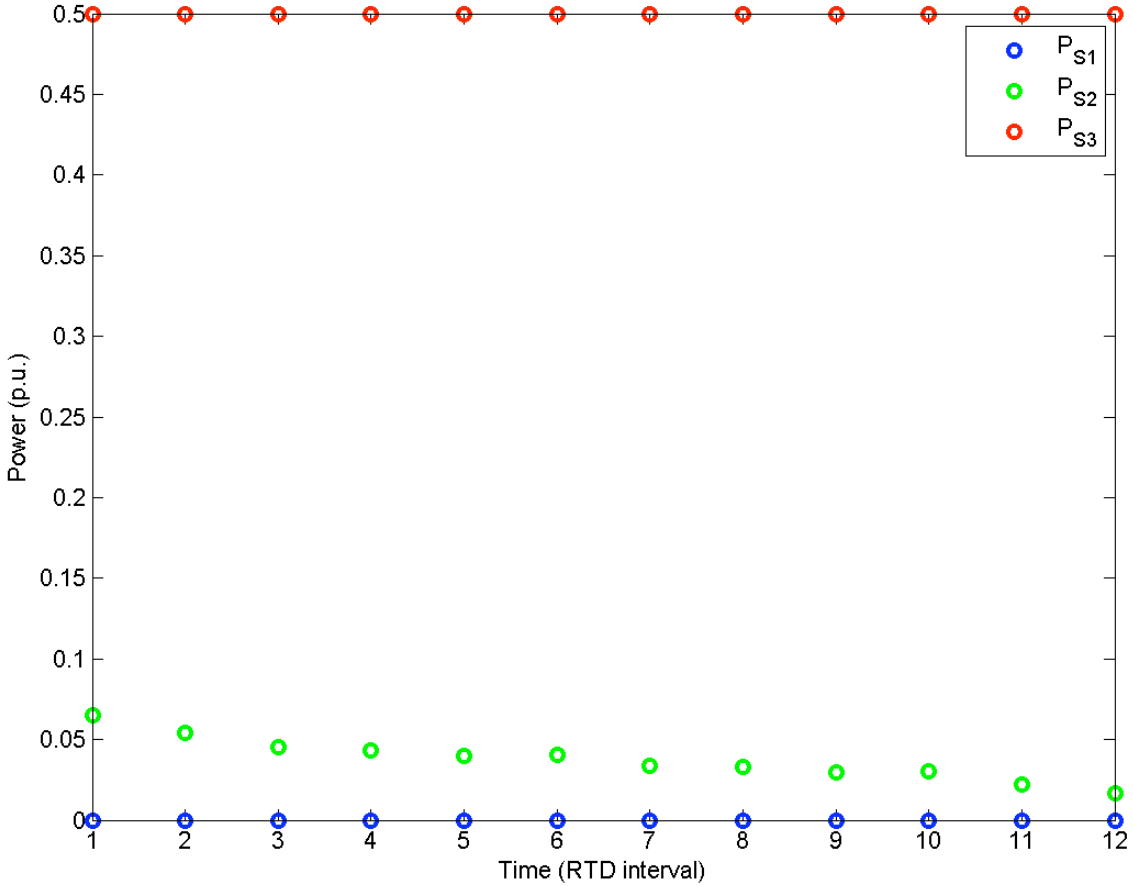
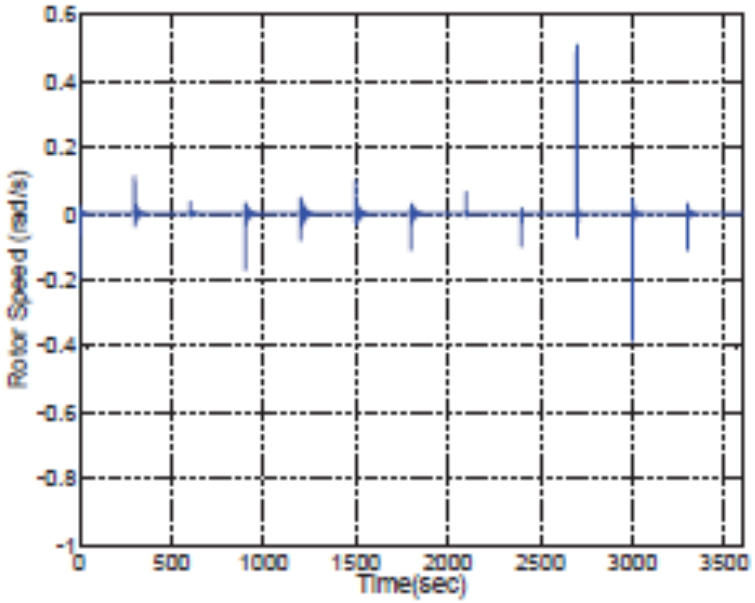
3	100	95%-105% of committed

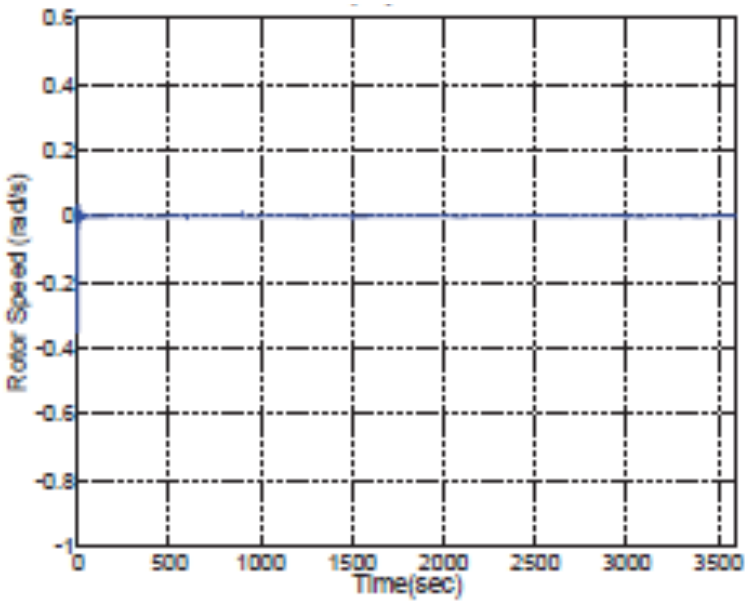


Applying Enhanced AGC in Real Time

- After robust economic dispatch is applies, less expensive resources need to be called in AGC



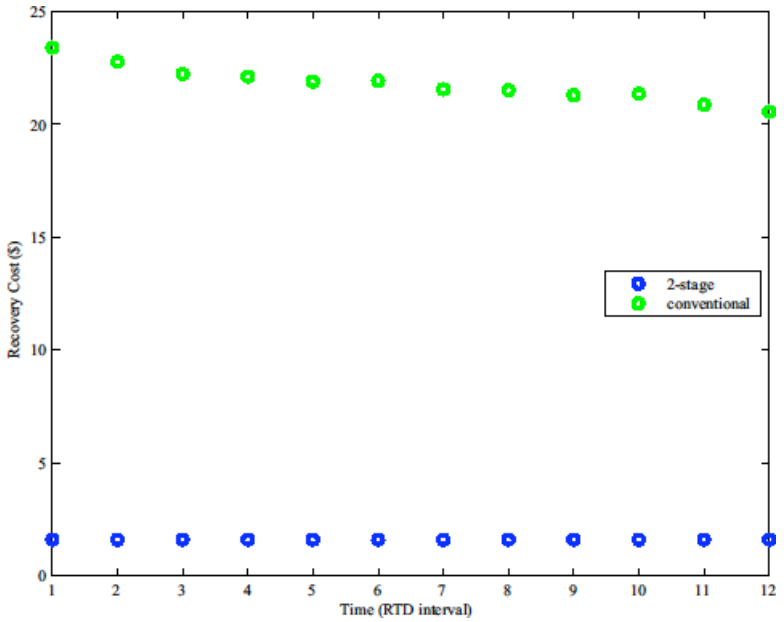
AGC control signal with conventional economic dispatch



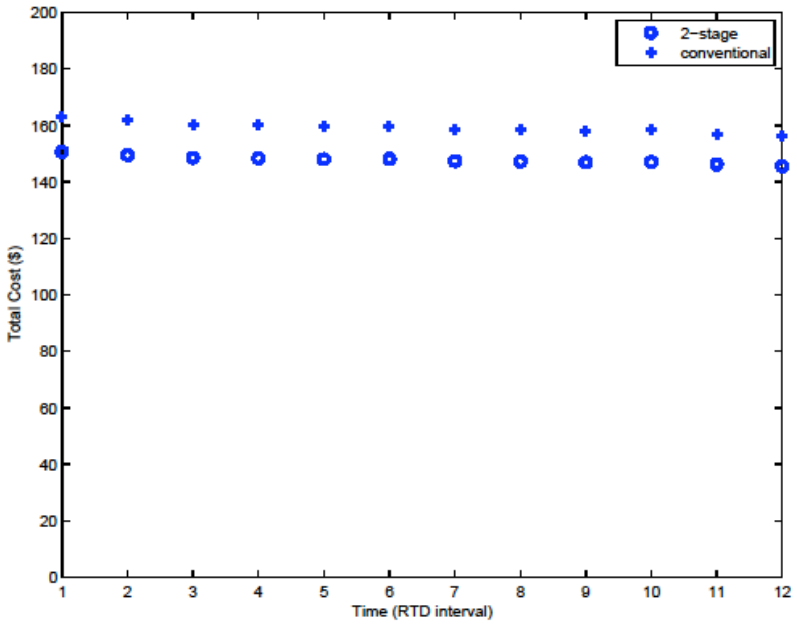
AGC control signal with robust economic dispatch

Cost Savings of Proposed Framework

- Proposed framework achieves lower recovery cost as well as total cost



Recovery Cost



Total Cost

Proposed Market Structure

Bid	Dispatch	Re-dispatch
• Slow generator creates bid based on risk preference • Fast generator creates bids for real-time market and re-dispatch market	• Before the beginning of 5-min interval, SO conducts real-time dispatch • **Real-time market clears**, obtain system price λ • **Demand pay generators** according to system price	• Right after the beginning of 5-min interval, SO re-dispatches fast generators to compensate deviations of slow generators • **Re-dispatch market clears**, obtain price for deviations α • **slow generators pay fast generators** for deviations

- Slow generator's total revenue: $\lambda P_i - \alpha \Delta P_i$
- Fast generator's total revenue: $\lambda P_i + \alpha \Delta P_i$
- Slow generator gets punished for deviations; Fast generator gets paid for compensating deviations in real-time.

Slow Generator's Profit Maximization

Bid | Dispatch | Re-dispatch

- Given system price λ, confidence level β_i, slow generator i wants to maximize its profit, taking into account potential re-dispatch costs

$$\max_{P_i[t]} \quad \lambda[t]P_i[t] - C_i(P_i[t]) - \boxed{VaR_{\beta_i}(\alpha[t]\Delta P_i[t])}$$

Value at Risk of potential re-dispatch cost

$$s.t. \quad P_i^{min} \le P_i[t] \le P_i^{max}$$

Capacity constraint

$$|P_i[t] - P_i[t-1]| \le RR_i$$

Ramp rate constraint

$$\Delta P_i[t] \sim f(\cdot; P_i[t])$$

p.d.f. of possible deviation

$$\alpha[t] \sim g(\cdot)$$

p.d.f. of re-dispatch price

- β_i controls risk preference of slow generator i
  - Risk takers: β_i small; Risk avoider: β_i large.

Creating Simple Bids

Bid → Dispatch → Re-dispatch

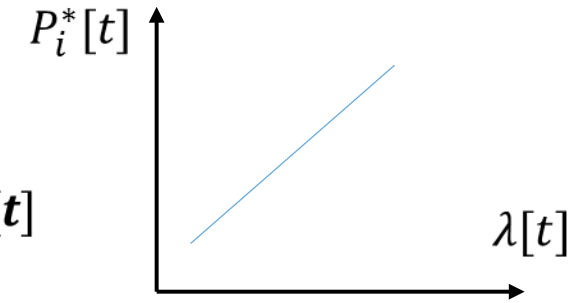
- Slow generator i creates its bid function based on price sensitivity

Given system price $\boldsymbol{\lambda[t]}$, slow generator's profit maximization

$$\max_{P_i[t]} \quad \lambda[t]P_i[t] - C_i(P_i[t]) - VaR_{\beta_i}(\alpha[t]\Delta P_i[t])$$
$$s.t. \quad P_i^{min} \le P_i[t] \le P_i^{max}$$
$$|P_i[t] - P_i[t-1]| \le RR_i$$
$$\Delta P_i[t] \sim f(\cdot; P_i[t])$$
$$\alpha[t] \sim g(\cdot)$$

Vary $\boldsymbol{\lambda[t]}$, compute $\boldsymbol{P_i^*[t]}$

"Simple bid" curve of slow generator $\boldsymbol{i}$



Or equivalently, Cost function $\boldsymbol{C_i'(P_i[t])}$

System Operator's Real-Time Dispatch Problem

Bid → Dispatch → Re-dispatch

- Robust real-time dispatch (Previously mentioned)

$$\max_{P_S,P_F} \quad C_S(P_S) + C_F(P_F) + R_{wc}(P_S, P_F; \hat{\Omega})$$

$$s.t. \quad \sum_{i=1}^{n_S} P_{Si} + \sum_{i=1}^{n_F} P_{Fi} = P_D$$

$$|F(P_S, P_F)| \le F^{max}$$

$$P_S^{min} \le P_S \le P_S^{max}, P_F^{min} \le P_F \le P_F^{max}$$

- SO's real-time dispatch with simple bids

$$\max_{P_S,P_F} \quad C'_S(P_S) + C_F(P_F)$$

Simple bid of slow generators

$$s.t. \quad \sum_{i=1}^{n_S} P_{Si} + \sum_{i=1}^{n_F} P_{Fi} = P_D$$

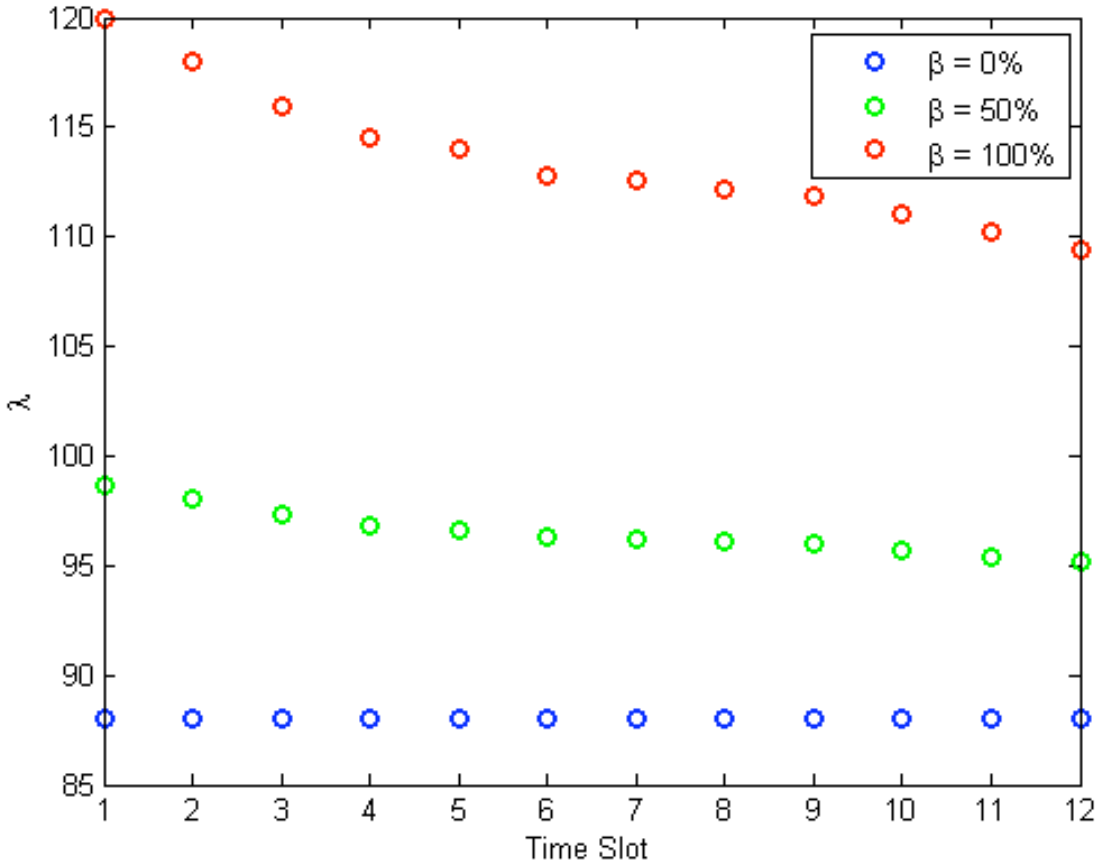
$$|F(P_S, P_F)| \le F^{max}$$

$$P_S^{min} \le P_S \le P_S^{max}, P_F^{min} \le P_F \le P_F^{max}$$

- With simple bid, SO only needs to solve static OPF, instead of two-stage robust OPF;
- SO's problem in simple bid yields the same solution when re-dispatch price can be predicted perfectly.

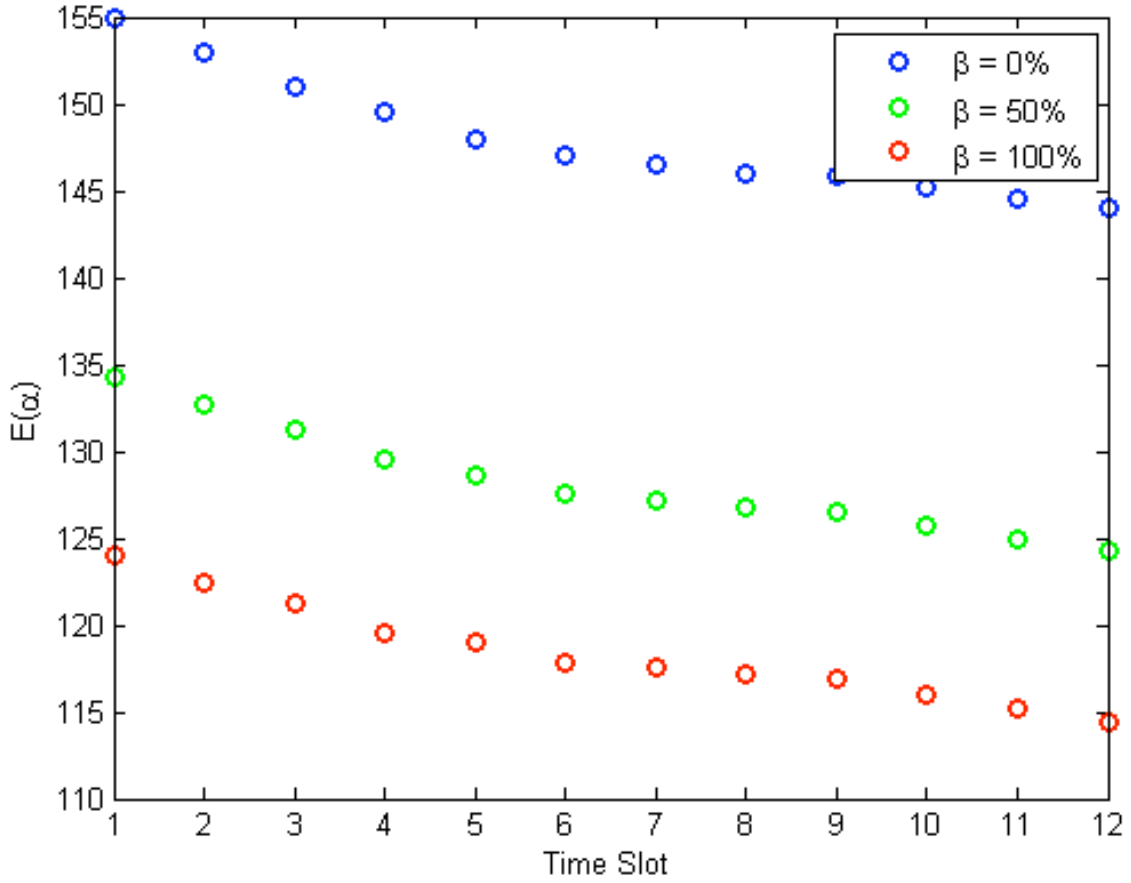
Impact of Slow Generator's Risk Preferences on System Price λ

- System price increases as generators are more risk averse



Impact of Slow Generator's Risk Preferences on Redispatch Price α

- Re-dispatch price decreases as generators are more risk averse



Reference

- Marija D. Ilić, Xiaoqi Yin, Qixing Liu, Yang Weng, Toward Combining Intra-Real Time Dispatch and AGC for Online Power Balancing, to appear in IEEE PES General Meeting, 2014

Thank you!