Robust Look-ahead Economic Dispatch in Real-Time Market

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Outline

- Introduction
- An illustrative example
- Mathematic formulation
- Methodology
- Numerical results
- Conclusion

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Uncertainties in Real-Time Market (RTM)

- Renewable energy resources
  - Total U.S. Wind power Capability reaches 47 GW in 2011
  - Wind power variations in short time [1]

Within the Minute	Within the Hour	From Hour to Hour
Quite Small	±5% of inst. Cap.	±20% of Inst. Cap.

- Load forecasting error
  - price-sensitive load

[1] European Wind Energy Association, *Wind Energy - The Facts: A Guide to the Technology, Economics and Future of Wind Power*, 1St Edition, Routledge, 2009.

Techniques/Strategies

- Stochastic SCUC based on scenarios
- Two-stage robust SCUC in DARU
- Look-ahead economic dispatch
- Ramping capability in system
- Load following capability
- Frequency regulation
- …

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An illustrative example

- Consider one-bus system with two generator

	Min (MW)	Max (MW)	Ramp (MW/h)	a ($/MW^2)	b ($/MW)	c ($)	Startup Cost ($)
Unit 1	30	90	15	0.001	13.5	176	180
Unit 2	40	100	15	0.004	32.6	129	90

- Load range in five intervals

Time	1	2	3	4	5
Lower bound (MW)	95	115	145	160	150
Upper bound (MW)	105	125	155	170	155

An illustrative example (Cont'd)

- Unit Commitment is determined (ALL ON)
- ED solution based on forecasted load

Time	Forecasted	Actual	Unit 1	Unit 2
1	105	105	65	40
2	115	115	75	40
3	145	145	90	55
4	160	170	90	70

How much?

Is it cost-effective?

Infeasible! Larger ramping capability is needed

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Formulation

- Two stages
  - First stage, with accurate predication
  - Second stage, with rough range of uncertain quantities
- Objective: minimize the total cost while considering the worst case

$$\min_{P_{iv}, v \in \Lambda} \left\{ \sum_i \sum_v f(P_{iv}) + \max_{\bar{d} \in D} \min_{P \in \chi(P_{iv})} f(P) \right\}$$

1. Feasibility
2. Cost-effective

Mathematic Formulation (Cont'd)

- Constraints in first-stage
  - Ramping limits, upper and lower bounds
  - Security constraints, load balance
  - Feasibility cuts, optimality cuts
- Constraints in second-stage

$$\chi(P_{i\tau}) = \left\{ \begin{array}{l} P \in R^{N\times T-\tau-j}: \\ \quad \tau + j \le t \le T \\ \quad P_{it} \le \hat{I}_{it} U_i, \quad \forall i,t \\ \quad -P_{it} \le -\hat{I}_{it} L_{it}, \quad \forall i,t \\ \quad P_{it} - P_{i(t-1)} \le RU_i \left(1-\hat{y}_{it}\right) + L_i \hat{y}_{it}, \quad \forall i,t \\ \quad -P_{it} + P_{i(t-1)} \le RD_i \left(1-\hat{z}_{it}\right) + L_i \hat{z}_{it}, \quad \forall i,t \\ \quad \sum_n SF_{ln} \left(\sum_i KP_{ni} P_{it} - \sum_m KD_{nm} d_{mt} \right) \le FL_l^{\max}, \quad \forall l,t \\ \quad \sum_n -SF_{ln} \left(\sum_i KP_{ni} P_{it} - \sum_m KD_{nm} d_{mt} \right) \le FL_l^{\max}, \quad \forall l,t \end{array} \right\}$$

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Benders Decomposition

- Basic idea is to generate properly cutting planes to eliminate the infeasible and non-optimal sets
  - Feasibility cuts
  - Optimality cuts

- "Mountain Climbing" procedure to solve the counterpart

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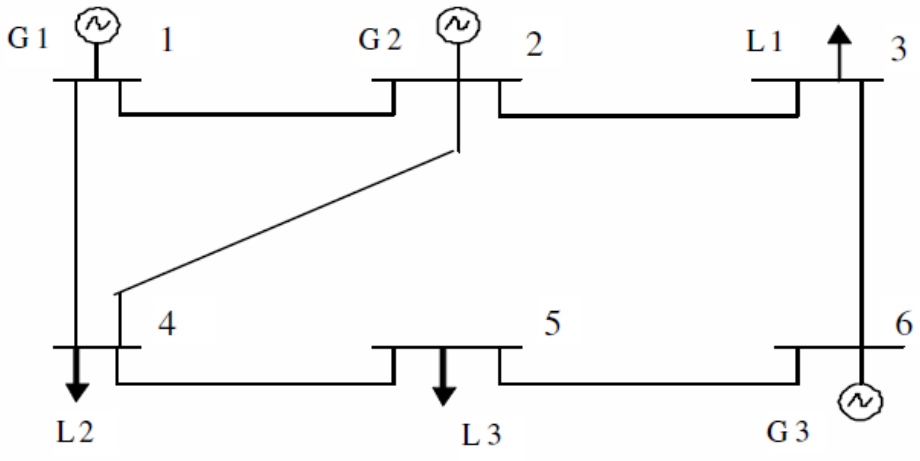
Six-Bus Case

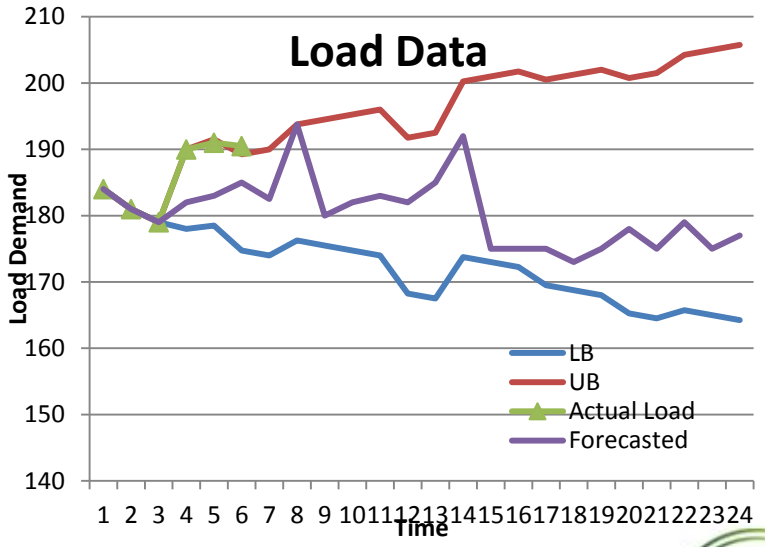
- Assume the predication of the next 15 minutes is accurate enough
- Unit Commitment is determined in DAM
- Time step is 5 minutes
- Compare the operation cost in the next30 minutes
- Run the RO Look-ahead ED twice

Six-Bus Case

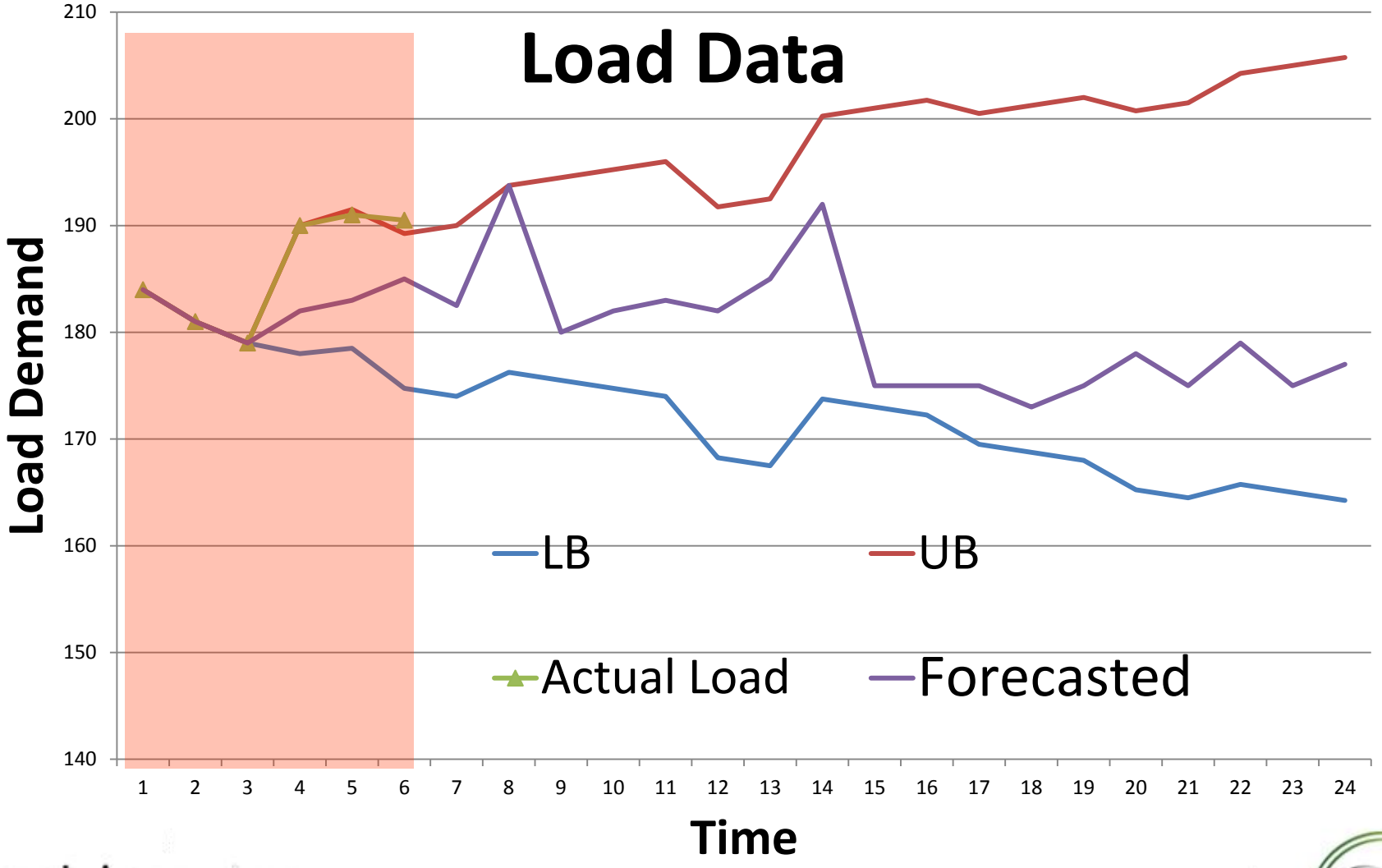


Gen No.	Bus No.	Pmax (MW)	Pmin (MW)	Ramp (MW/5min)
1	1	180	100	15
2	2	100	10	8
3	6	80	10	8

Line	from	to	x	Rate(MW)
1	1	2	0.170	200
2	1	4	0.258	83
3	2	3	0.037	200
4	2	4	0.197	100
5	3	6	0.018	100
6	4	5	0.037	200
7	5	6	0.140	100



Six-Bus Case


Load Data
Load Demand
Time
210
200
190
180
170
160
150
140
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
LB
UB
Actual Load
Forecasted

Six-Bus Case

- Robust Look-ahead V.S. Look-ahead

	Robust Look-Ahead		Look-Ahead	
	Unit 1(MW)	Unit 2(MW)	Unit 1(MW)	Unit 2(MW)
1	172	12	172	12
2	171	10	171	10
3	166.411	12.589	169	10
4	169.521	20.479	170.476	18
5	169.04	21.96	169.04	21.96
6	169.281	21.219	169.281	21.219
Curt. (MW*5min)	0		1.524	
Cost($)	2633.776		3081.741	

Spinning reserves are above 80 MW

CPU time is less than 0.2 s

Six-Bus Case

- DC Power Flow in Line 2

T	1	2	3	4	5	6
RO Look-ahead (MW)	82.87	82.09	80.36	83	83	83
Look-ahead (MW)	82.87	82.09	81.15	83	83	83

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Conclusion

- Robust look-ahead ED in RTM can effectively relieve the infeasibility pressure caused by the large variation and uncertainties in system
- No probability distribution is needed
- RO Look-ahead ED also brings economic benefits
- Fast-start generators will be included

Thanks!