Uncertainty in Unit Commitment Models

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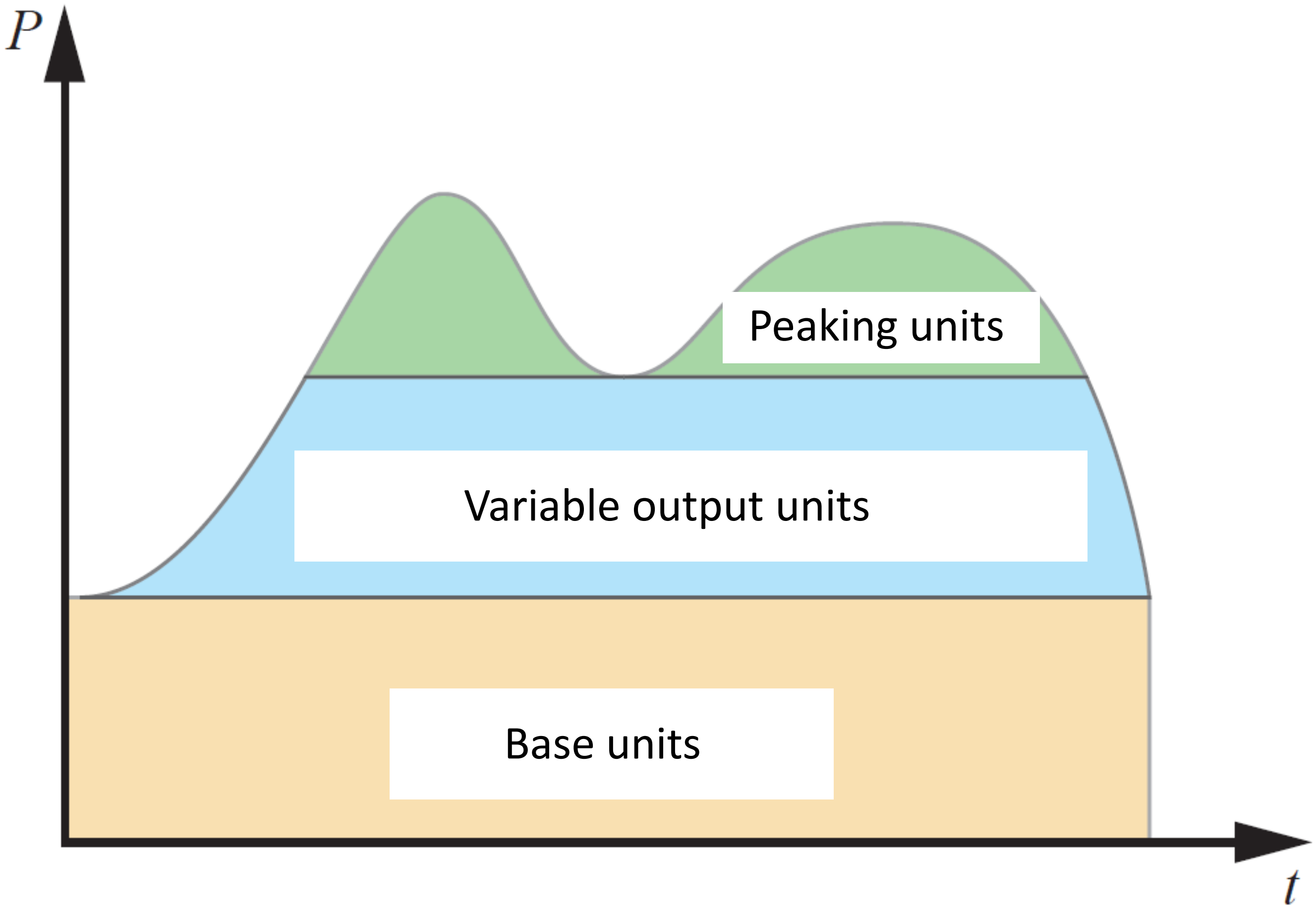
Mathematical Modeling in Power Systems Workshop
Zagre, June 28, 2016

What is Unit Commitment

- System operation planners decide on the generating unit on/off statuses for the following day
- Based on the load predictions (temperature, historical data)
- Low mistakes (<1%)

What is Unit Commitment



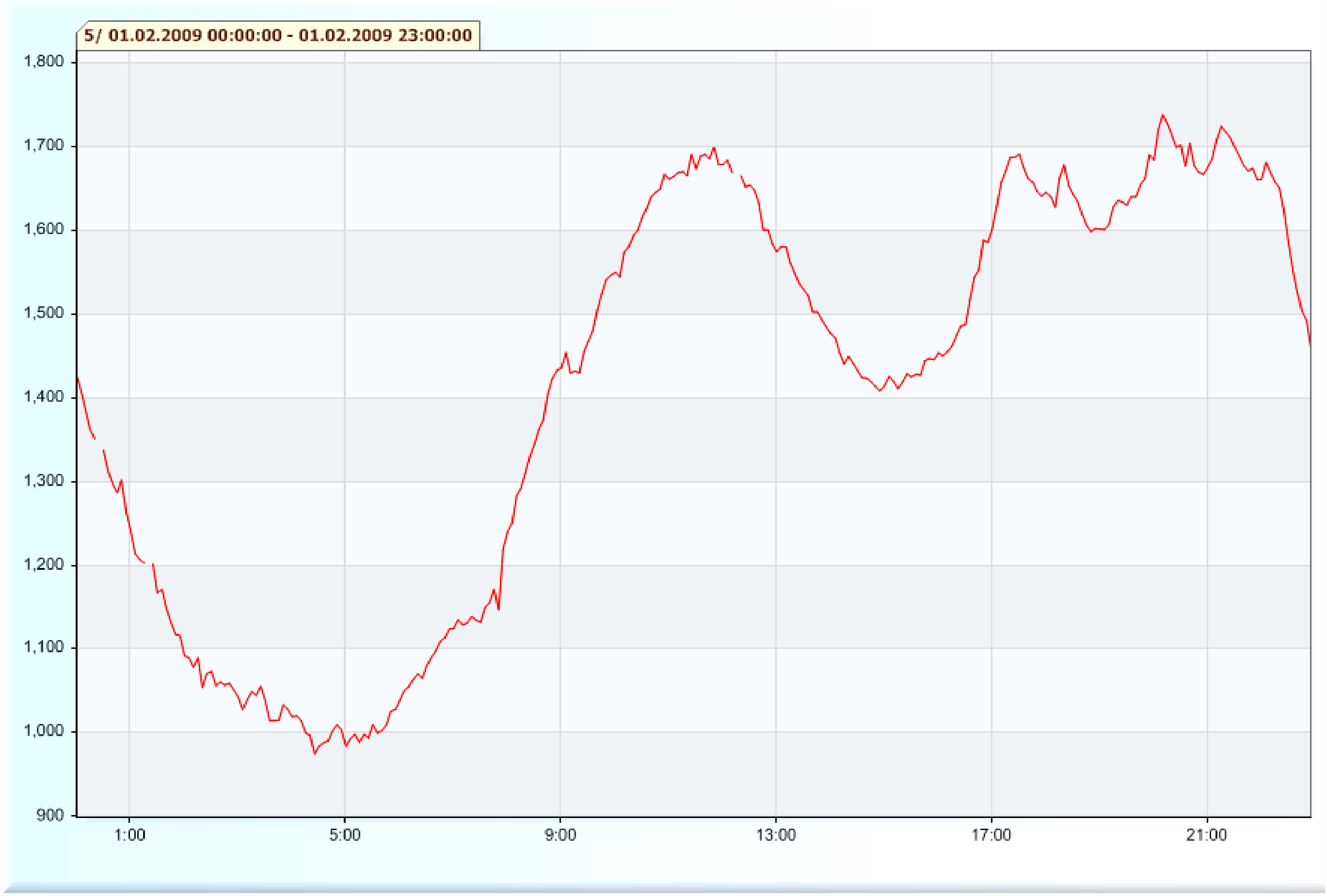
What is Unit Commitment

- In real time, system operators run the power system according to the day-ahead schedule
- They deal with predicted load curve errors by:
  - redispatching online units
  - committing fast units
  - load shedding

Dispatch Center

Sport Events

- WC Handball Finals: Croatia – France (Sunday, Feb. 1, 2009)



Sport Events

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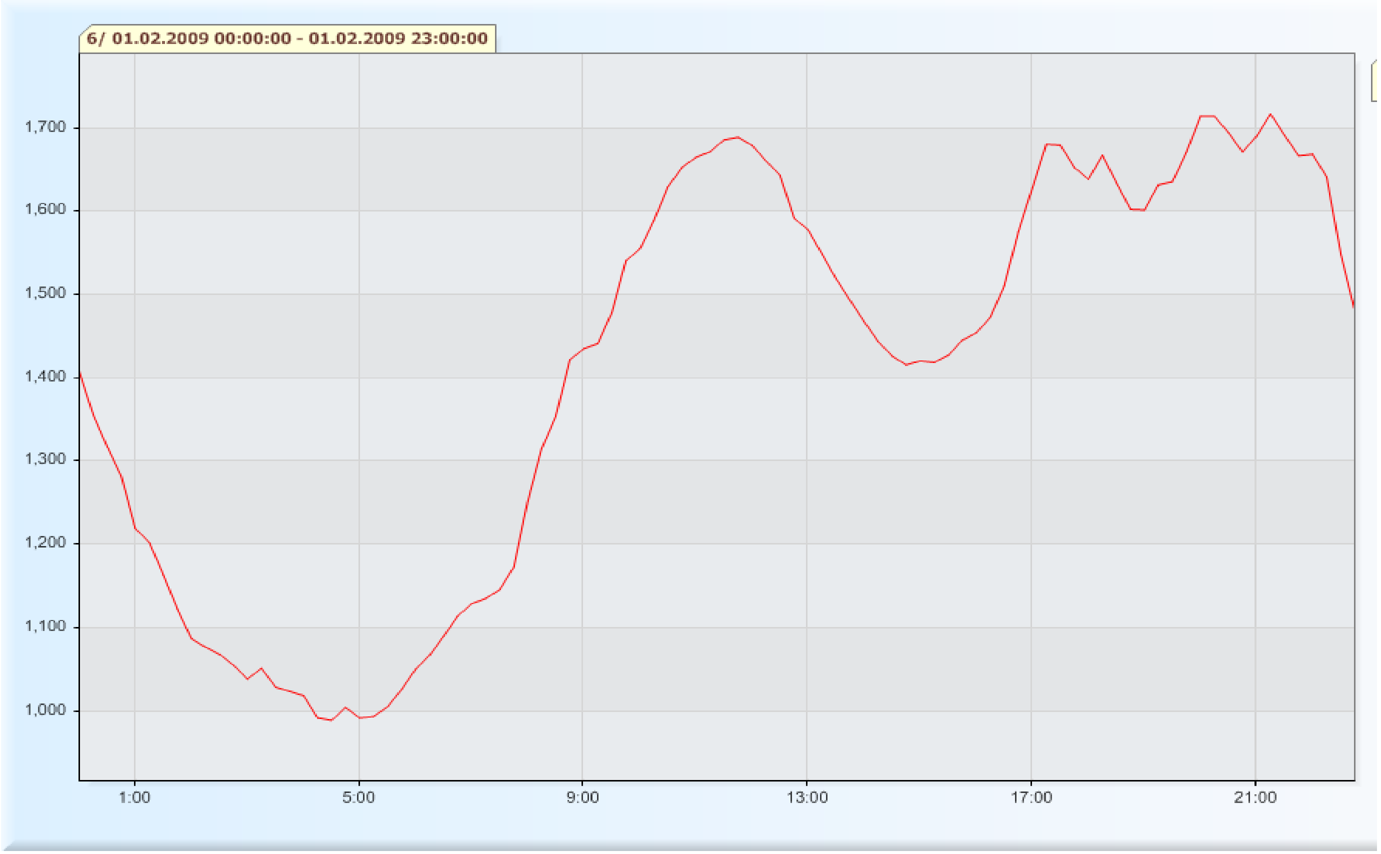
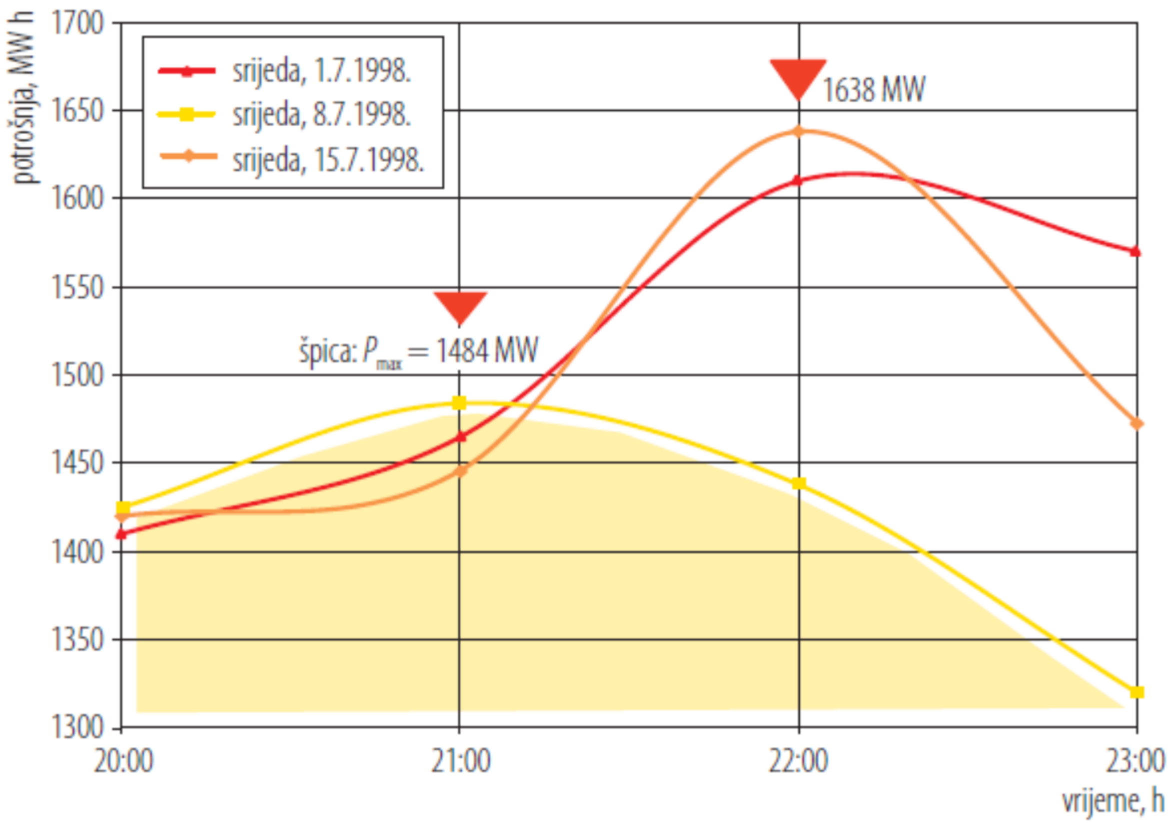


Sport Events

- WC Soccer Semi-Finals: Croatia – France (Wed., July 8, 1998)



Niko Mandić, „What connects soccer and power system?," EGE 3/2008, pp. 44-50

Sport Events

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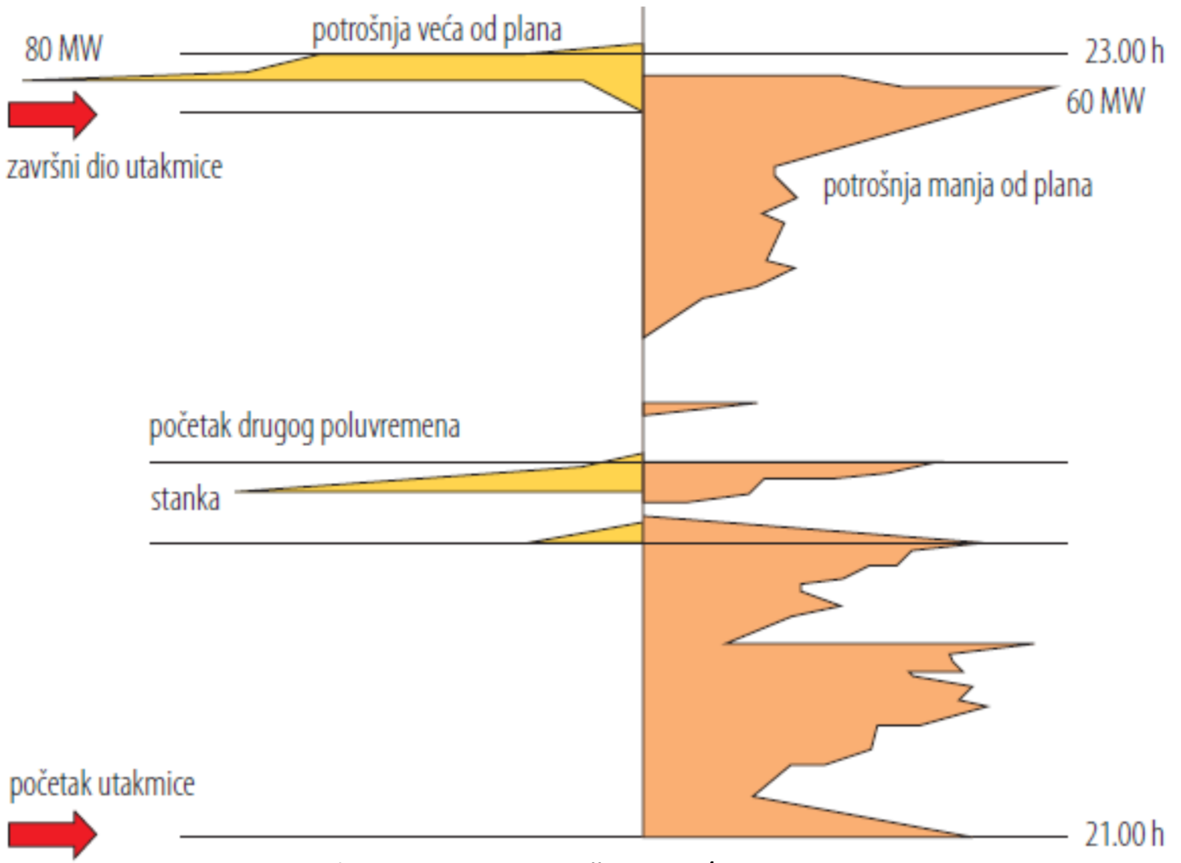

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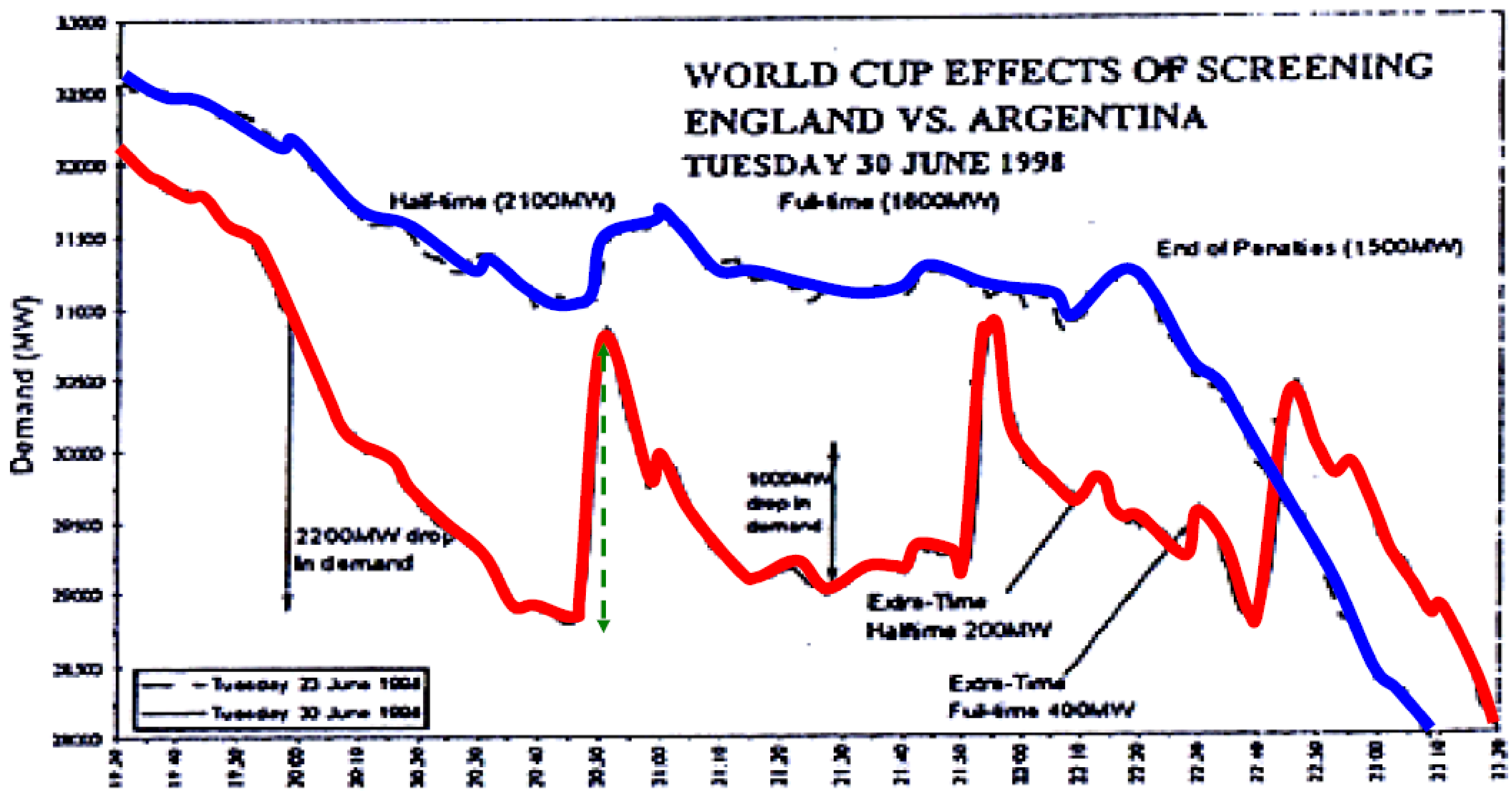
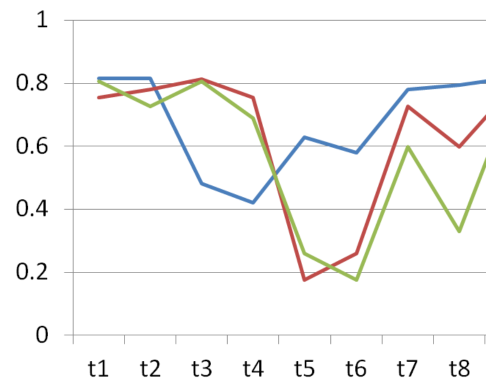
Sport Events

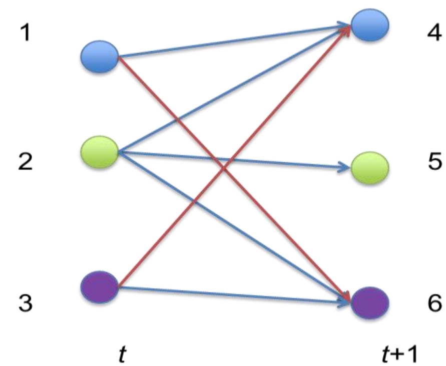


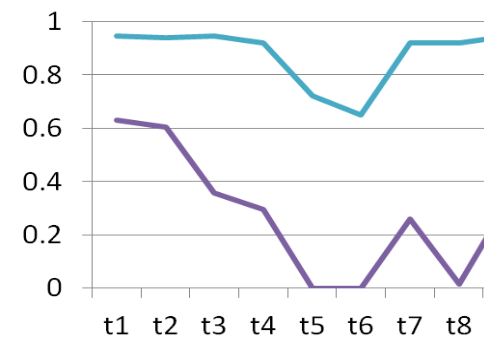
Introduction to Unit Commitment

- Integration of wind farms makes day-ahead planning more difficult as wind forecasts are not entirely certain
- Wind uncertainty needs to be added on top of the load uncertainty
- What are the options to deal with this high uncertainty?

Unit Commitment Techniques

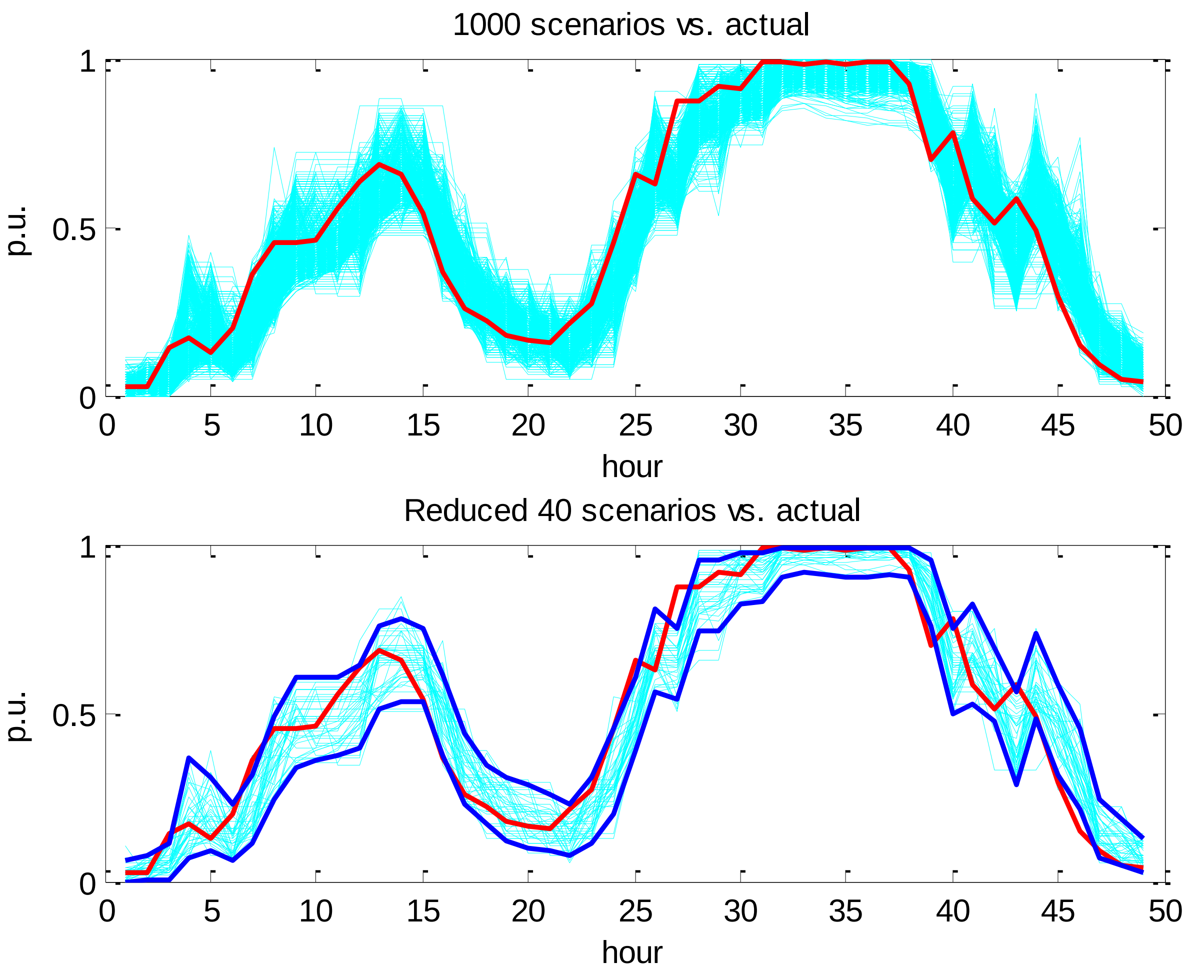






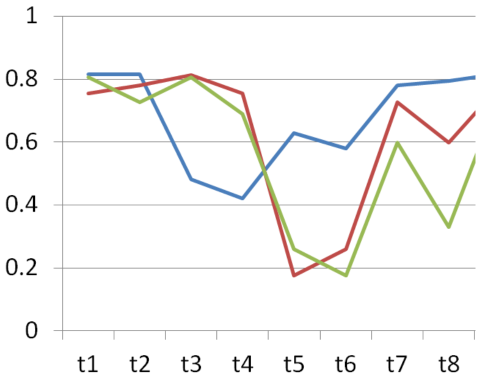
	Stochastic	Interval	Robust
Uncertainty	Scenarios	Uncertainty range	Uncertainty range
Objective (Minimize)	The expected cost of the scenarios considered	The cost of the most likely wind forecast	The highest cost among all realizations
Robustness	Increases with the number of scenarios	High	High
Computation time	Higher	Lower	Depends on the worst scenario searching process

Scenario Generation



- Remaining issues:
  - ➢ How to reduce scenario better?
  - ➢ How to estimate bounds better?

Stochastic Optimization



Stochastic

Scenarios

The expected cost of the scenarios considered

- **Minimize**: Cost(Dispatch, ON/OFF)
- **System balance**:

  Generation Supply = Demand – Wind
- **Physical constraints of generators**
- **Transmission capacity**

$$\min_{p_{i,t,n},x_{i,t}} \quad E\left[C\left(p_{i,t,n}\right)\right]+S\left(x_{i,t}\right)$$

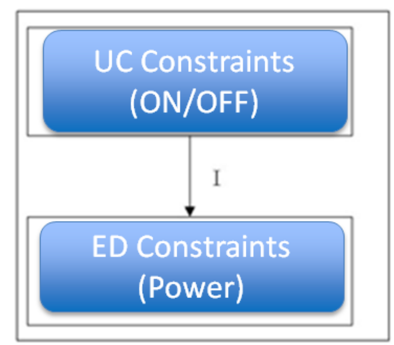
$$\sum_{i=1}^{I} p_{i,t,n} = D_t - \sum_{w=1}^{W} g_{w,t,n}$$

$$H\left(p_{i,t,n},x_{i,t}\right)=0, B\left(x_{i,t}\right)=0$$

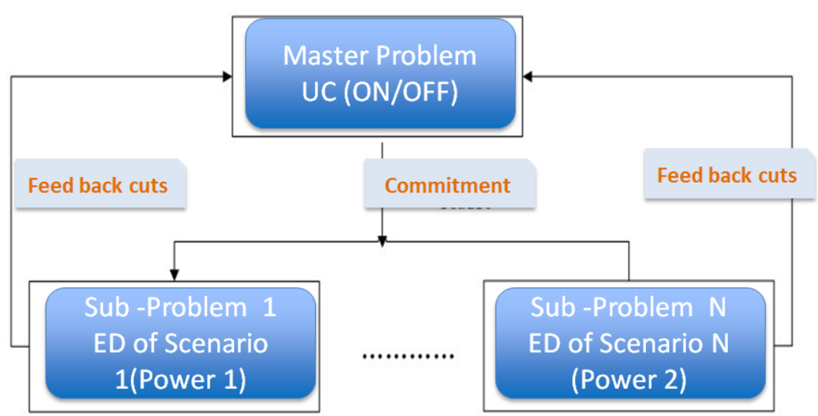
$$F\left(p_{i,t,n},g_{i,t,n}\right)=0$$

$$n=1..N$$

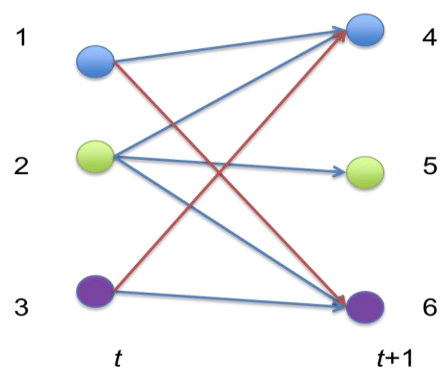
Centralized method



Decomposed method



Interval Optimization



- **Minimize:** Cost(Dispatch, ON/OFF)
- **System balance:**
  Generation Supply = Demand – Wind
- **Physical constraints of generators**
- **Transmission capacity**

$$\min_{p_{i,t,n},x_{i,t}} \quad C\left(p_{i,t,2}\right)+S\left(x_{i,t}\right)$$

$$\sum_{i=1}^{I} p_{i,t,n} = D_t - \sum_{w=1}^{W} g_{w,t,n}$$

$$H\left(p_{i,t,n},x_{i,t}\right)=0, B\left(x_{i,t}\right)=0$$

$$F\left(p_{i,t,n},g_{i,t,n}\right)=0$$

$$n=1,2,3$$

Interval
Scenarios
The cost of the most likely wind forecast

Transitions

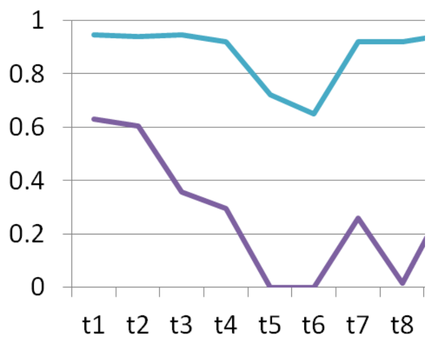
$1-6 \qquad \left|p_{i,t,1}-p_{i,t+1,3}\right| \le \Delta_i$

$2-6 \qquad \left|p_{i,t,2}-p_{i,t+1,3}\right| \le \Delta_i$

$2-4 \qquad \left|p_{i,t,2}-p_{i,t+1,1}\right| \le \Delta_i$

$3-4 \qquad \left|p_{i,t,3}-p_{i,t+1,1}\right| \le \Delta_i$

Robust Optimization



- **Minimize**: Cost(Dispatch, ON/OFF)
- **System balance**:
  Generation Supply = Demand – Wind
- **Physical constraints of generators**
- **Transmission capacity**

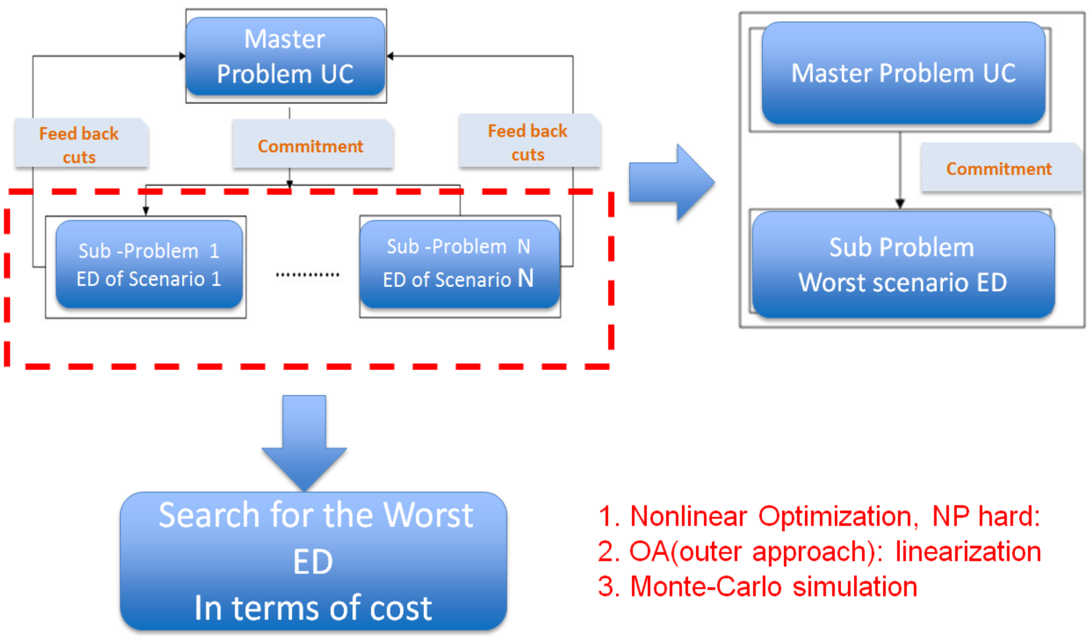
$$\min_{x_{i,t}} \max_{n} \left[\min_{p_{i,t,n}} C\left(p_{i,t,2}\right) \right] + S\left(x_{i,t}\right)$$

$$\sum_{i=1}^{I} p_{i,t,n} = D_t - \sum_{w=1}^{W} g_{w,t,n}$$

$$H\left(p_{i,t,n}, x_{i,t}\right) = 0, B\left(x_{i,t}\right) = 0$$

$$F\left(p_{i,t,n}, g_{i,t,n}\right) = 0$$

$$n = 1..\infty$$

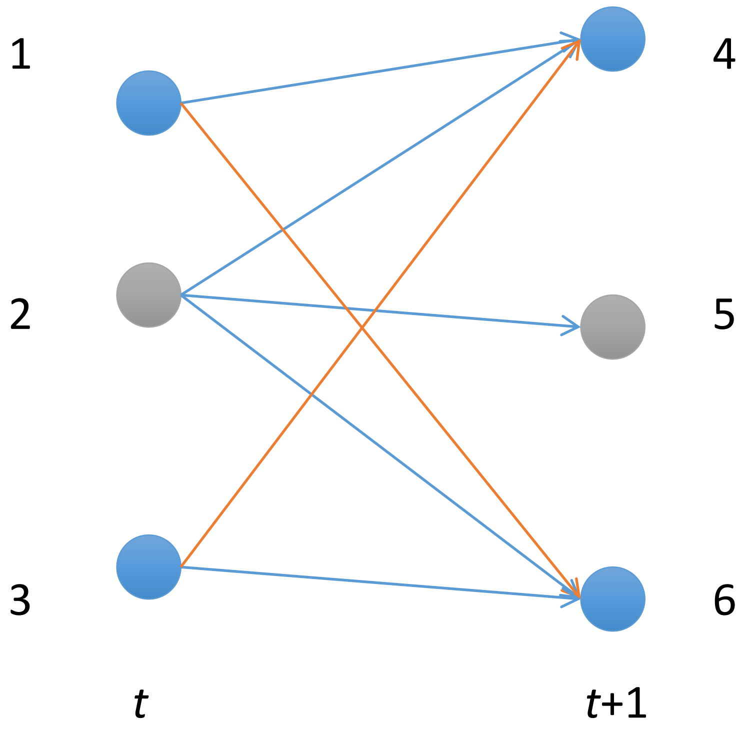


1. Nonlinear Optimization, NP hard:
2. OA(outer approach): linearization
3. Monte-Carlo simulation

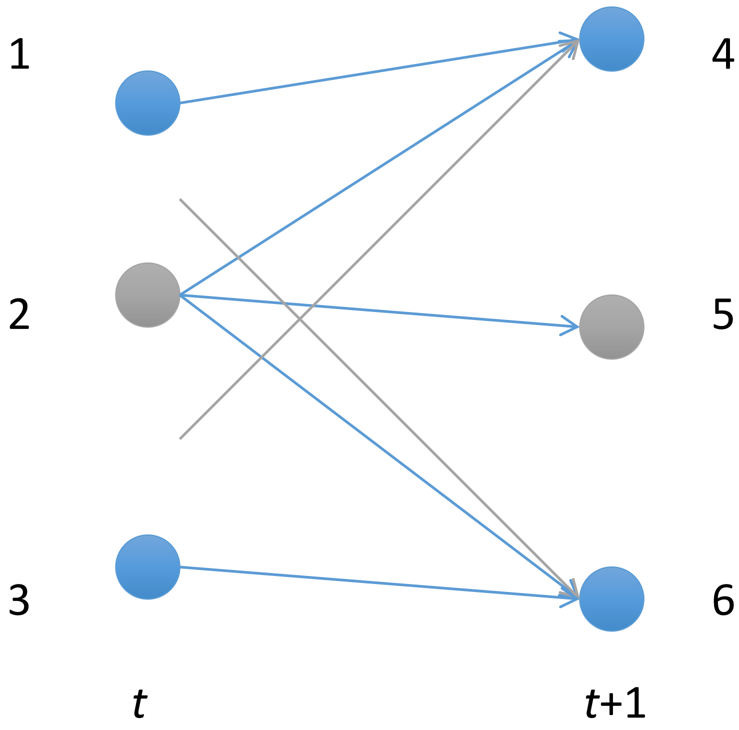
What Works Best?

Introducing Improved IUC

Interval UC



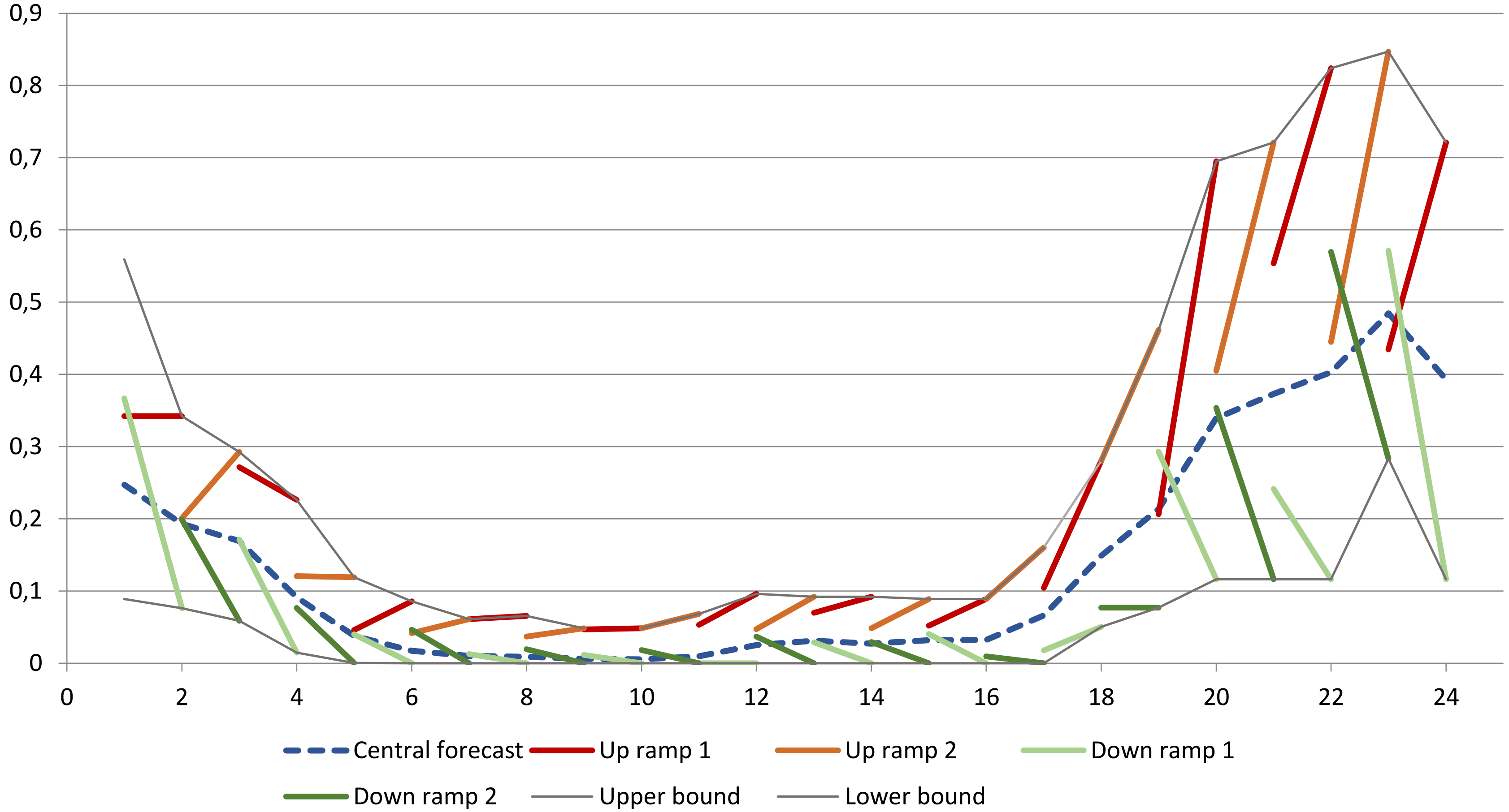
“Improved” Interval UC



Introducing Improved IUC

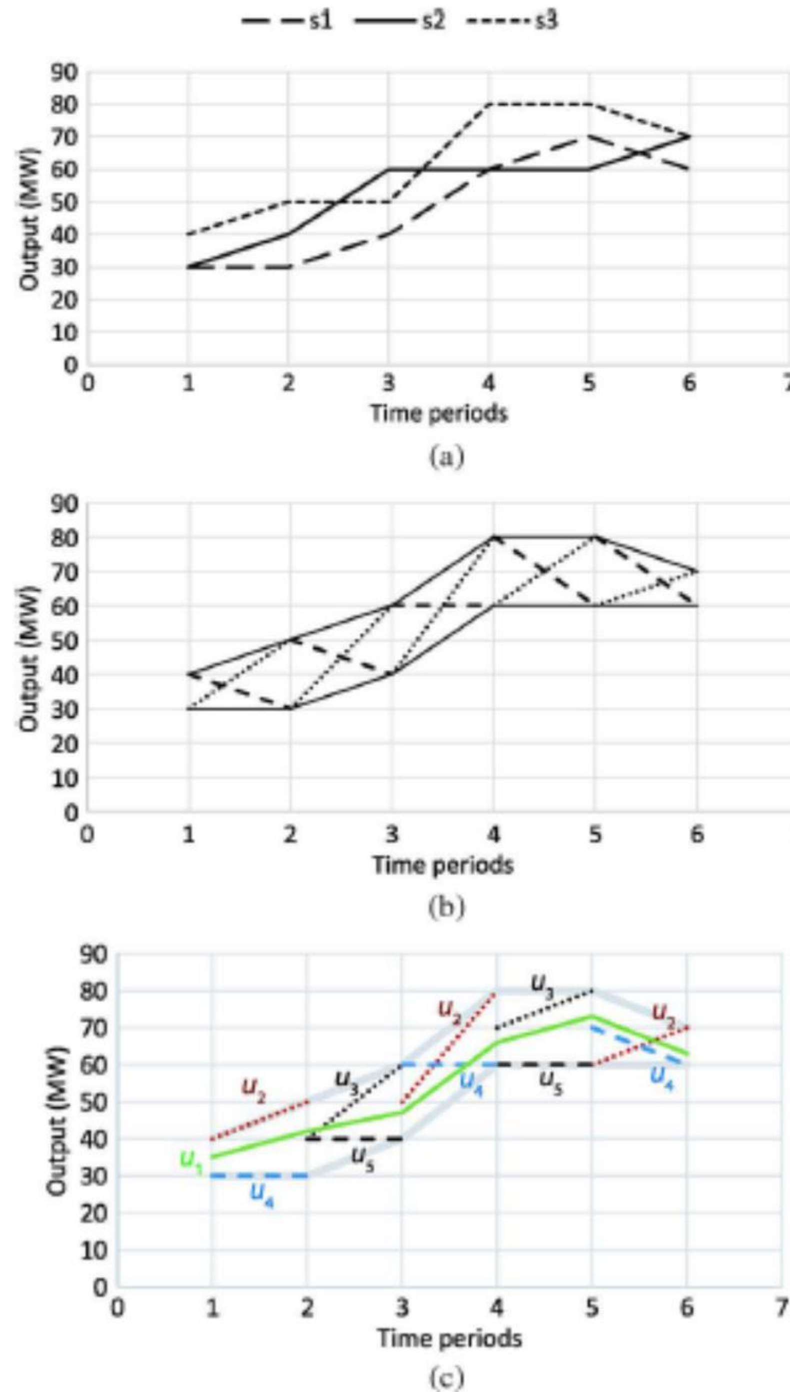
- Since we have 5 points at each time period, we use five scenarios:
  - Central forecast,
  - Up ramp 1 (enforced only between hours 1-2; 3-4; 5-6; etc.),
  - Up ramp 2 (enforced only between hours 2-3; 4-5; 6-7; etc.),
  - Down ramp 1 (enforced only between hours 1-2; 3-4; 5-6; etc.),
  - Down Up ramp 2 (enforced only between hours 2-3; 4-5; 6-7; etc.)
- It is not possible to use a single scenario for up or down rampings because that scenario would have two values for each hour
- This results in higher computational burden as compared to the IO, which uses only three scenarios, but the obtained solution is less conservative

Introducing Improved IUC

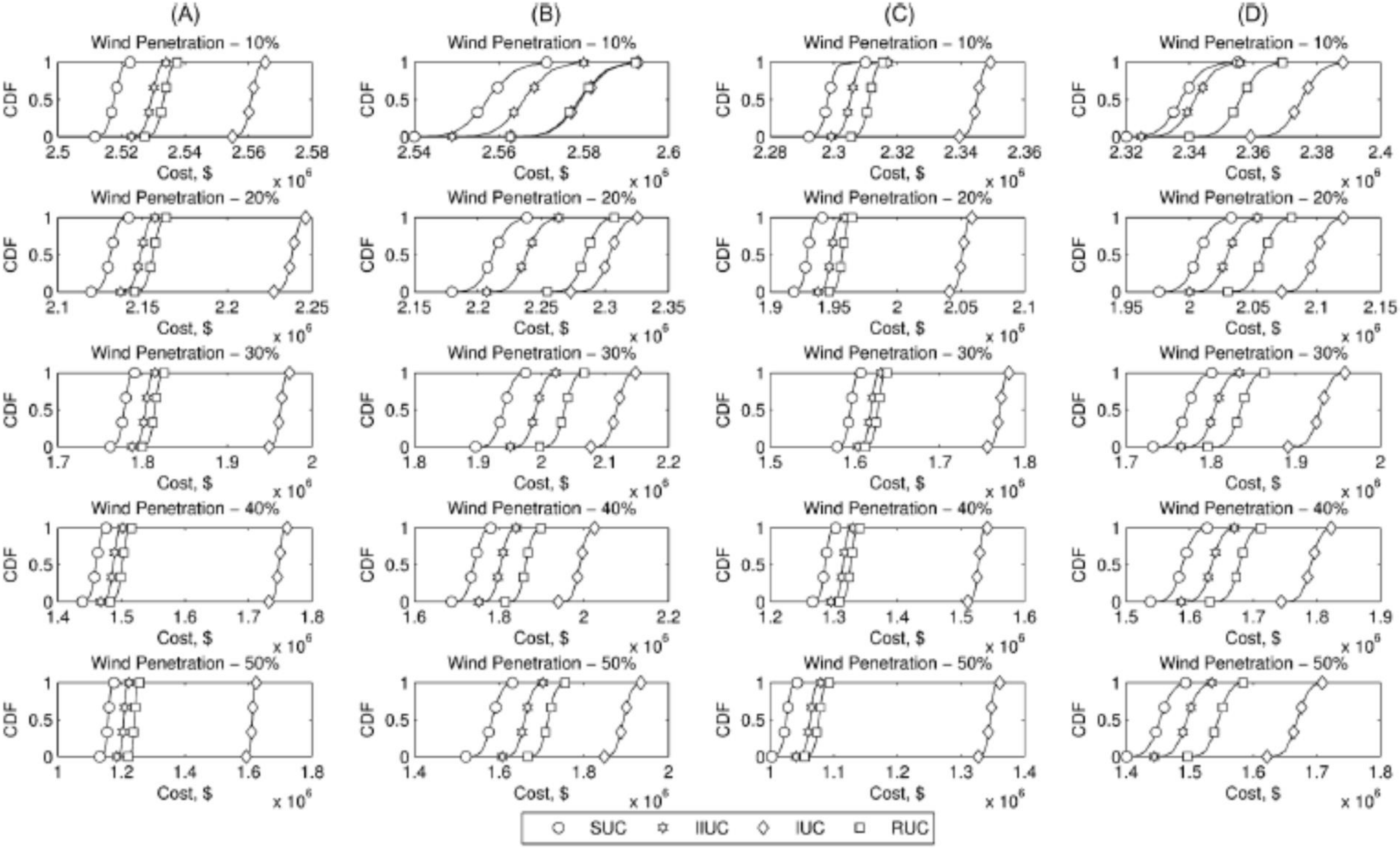


Illustrative Example

a) Three scenarios
b) Boundaries
c) IIUC „scenarios”



Case Study Results

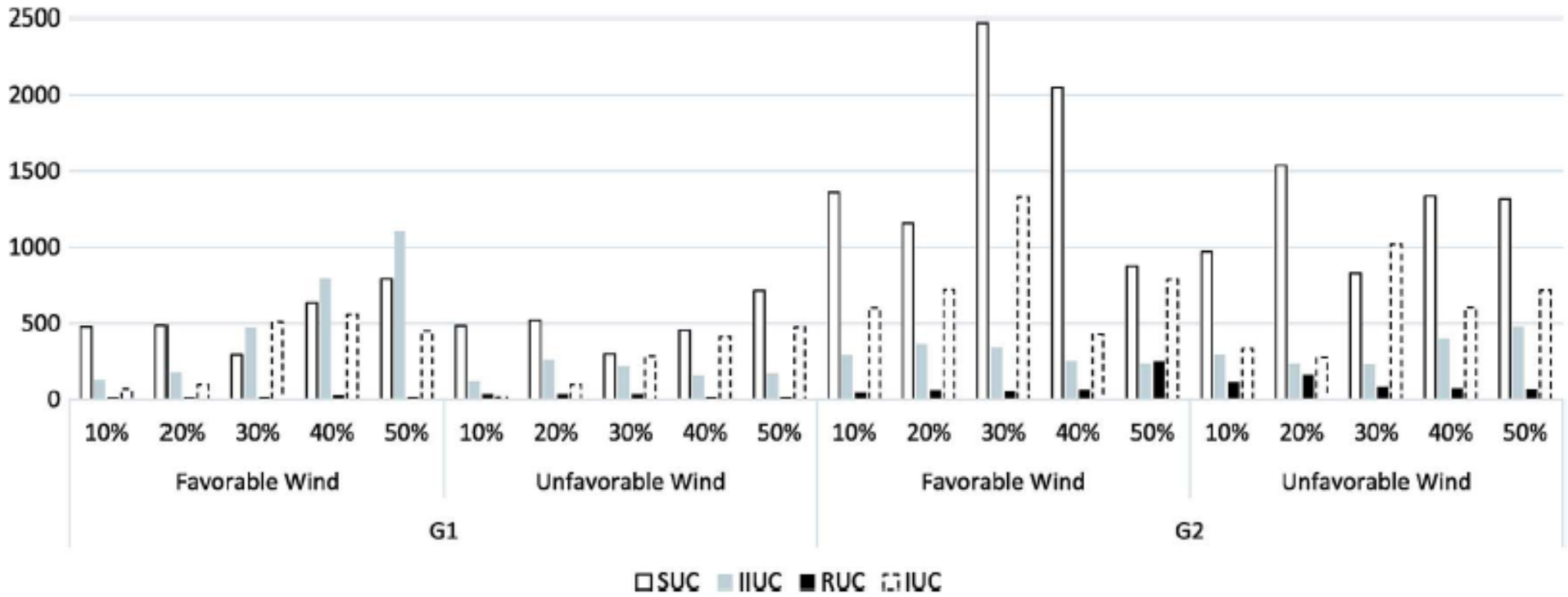


Case Study Results

COMPARISON OF ENERGY IMBALANCES (EWS—EXPECTED WIND SPILLAGE; EENS—EXPECTED ENERGY NOT SERVED)

			10%		20%		30%		40%		50%	
			EWS, MWh	EENS, MWh (freq.)	EWS, MWh	EENS, MWh (freq.)	EWS, MWh	EENS, MWh (freq.)	EWS, MWh	EENS, MWh (freq.)	EWS, MWh	EEN,S MWh (freq.)
G1	Favorable	SUC	0	0.009 (1)	0	0.008 (6)	0	0.005 (6)	20	0 (0)	62	0 (0)
		IIUC	0	0.001 (2)	0	0 (0)	0	0 (0)	0	0 (0)	59	0 (0)
		RUC*	0	0 (0)	0	0 (0)	0	0 (0)	8	0 (0)	383	0 (0)
		IUC	0	0 (0)	0	0 (0)	0	0 (0)	3	0 (0)	3,294	0 (0)
	Unfavorable	SUC	0	0.007 (6)	16	0.004 (2)	1,124	0 (0)	5,044	0 (0)	12,161	0 (0)
		IIUC	0	0 (0)	20	0 (0)	1,134	0 (0)	5,215	0 (0)	12,736	0 (0)
		RUC*	0	0 (0)	98	0 (0)	1,717	0 (0)	6,845	0 (0)	14,427	0 (0)
		IUC	0	0 (0)	16	0 (0)	2,457	0 (0)	10,166	0 (0)	19,735	0 (0)
G2	Favorable	SUC	0	0.045 (22)	0	0.038 (21)	0	0.012 (9)	9	0.009 (8)	211	0.008 (6)
		IIUC	0	0.043 (17)	0	0.034 (14)	0	0.011 (8)	1	0.007 (6)	151	0 (0)
		RUC*	0	0 (0)	0	0 (0)	0	0 (0)	2	0 (0)	271	0 (0)
		IUC	0	0 (0)	0	0 (0)	0	0 (0)	3	0 (0)	444	0 (0)
	Unfavorable	SUC	0	0.035 (17)	31	0.033 (20)	1,965	0.021 (10)	6,432	0.021 (18)	13,462	0.010 (10)
		IIUC	0	0 (0)	40	0 (0)	1,973	0 (0)	6,527	0 (0)	13,846	0 (0)
		RUC*	0	0 (0)	118	0 (0)	2,366	0 (0)	7,396	0 (0)	15,080	0 (0)
		IUC	0	0 (0)	67	0 (0)	2,883	0 (0)	9,650	0 (0)	18,099	0 (0)

Case Study Results



Wall-clock times in seconds required to reach 1% optimality gap for different wind penetration levels.

The End

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Thank you for your attention