eprice

ENABLING THE FUTURE ENERGY SYSTEM

E-PRICE Project overview

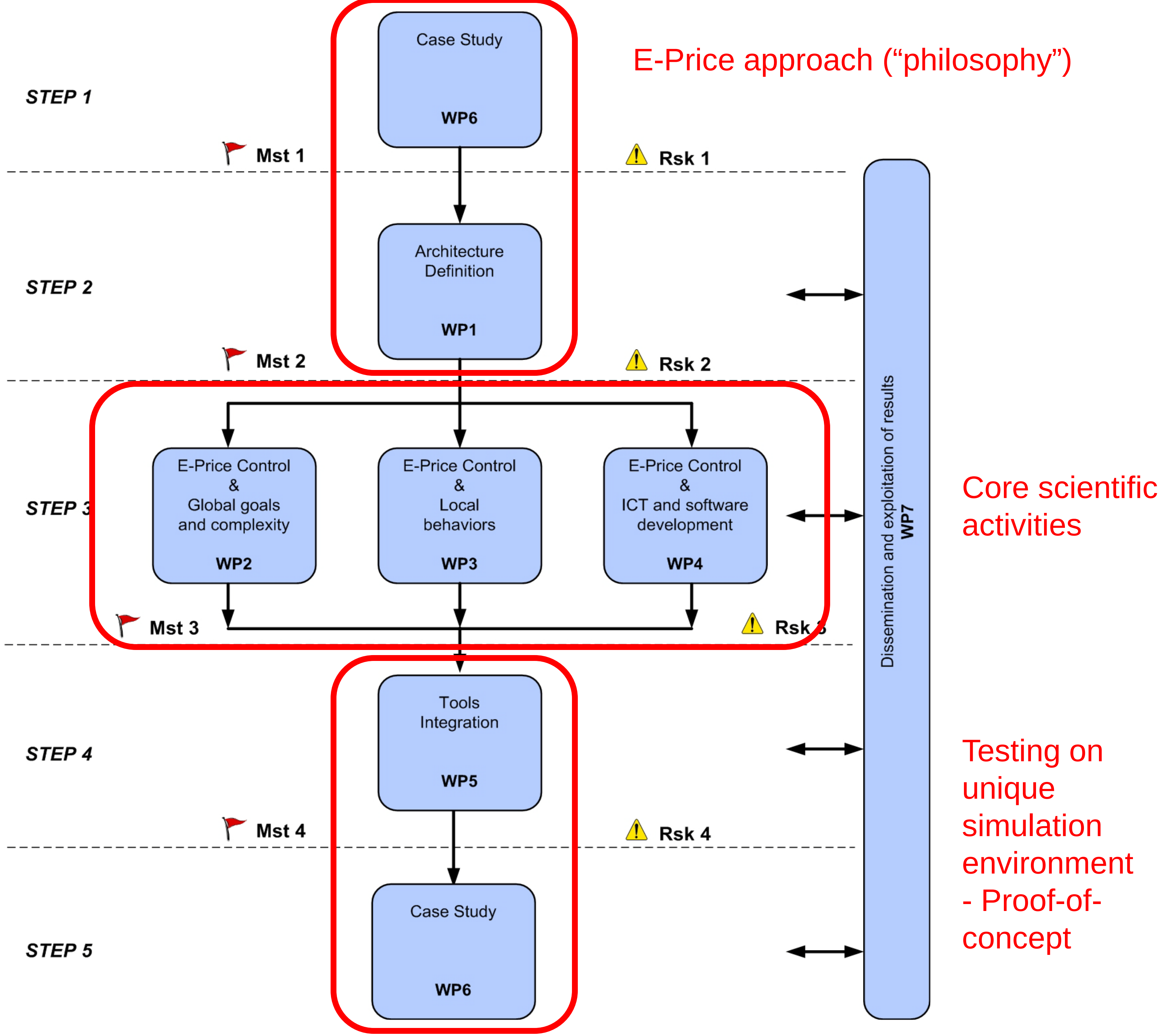
Efficiency, reliability and scalability of power systems

Accounting for trade-offs

Presenter: Andrej Jokić

E-Price Consortium

Eindhoven University of Technology	TU/e CS - EPS
Institute for Advanced Studies Lucca	IMTL
Eidgen. Tech. Hochschule Zurich	ETHZ
University of Zagreb	UNIZAG - FSB
ABB	ABB
APX-Group	APX
KEMA N.V.	KEMA M&R - FES
Operational Research Systems	ORS
TenneT Holding B.V.	TenneT



E-Price approach ("philosophy")
STEP 1
Case Study
WP6
Mst 1
Rsk 1
STEP 2
Architecture Definition
WP1
Mst 2
Rsk 2
STEP 3
E-Price Control & Global goals and complexity
WP2
E-Price Control & Local behaviors
WP3
E-Price Control & ICT and software development
WP4
Mst 3
Rsk
Core scientific activities
STEP 4
Tools Integration
WP5
Mst 4
Rsk 4
STEP 5
Case Study
WP6
Dissemination and exploitation of results
WP7
Testing on unique simulation environment - Proof-of-concept

Outline

- Motivation; problems and challenges
- E-Price approach
- Overview of results
- In some more detail:
  - double sided AS markets
  - spatial dimension of energy and AS trading
- Trade-offs (reliability, efficiency, complexity)
- Conclusions

Scope and Focus E-Price

Time axis 1 sec <> 1 day

Control	1 sec <> 15 minutes	Primary, Secondary Control
Markets	15 minutes <> 1 day	Energy, Ancillary Services

Relevant parties:

TSO	The System Operator
AS/EX Markets	
BRP	Balance Responsible Party (= BRP)

and

Prosumers

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Scope and Focus E-Price

Focus on Ancillary Services:

Real power, phase angles

Power network, grid

Global level: TSO, BRP, Markets

”Optimal” compromise between Reliability and Economy

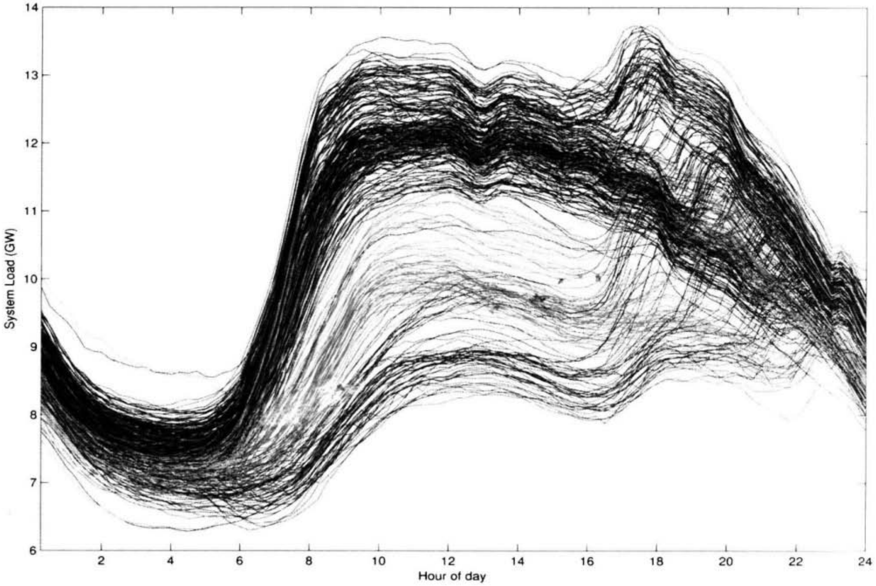
By purpose neglect:

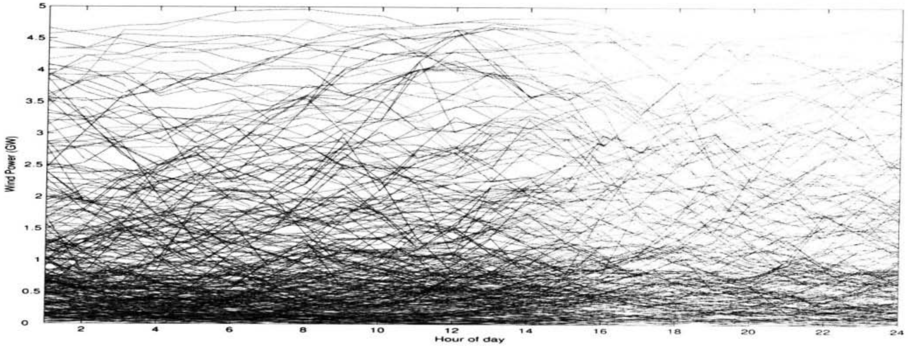
Reactive power, voltages (too fast, complex)

Distribution (DSO, ..)

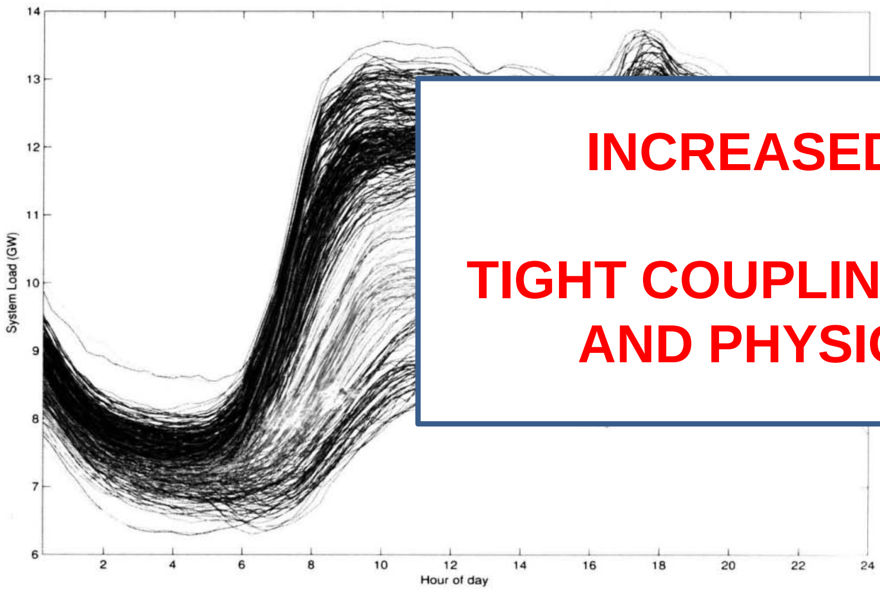
Protection (too fast)

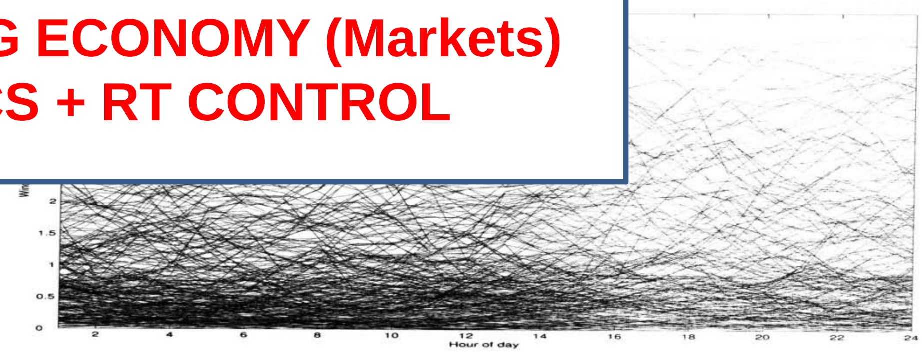
Investment (too slow)





In operation and control of future power systems, we will be forced to rely much more on holistic scientific solutions and much less on experience which will be both scarce and cryptic (unclear how to exploit).

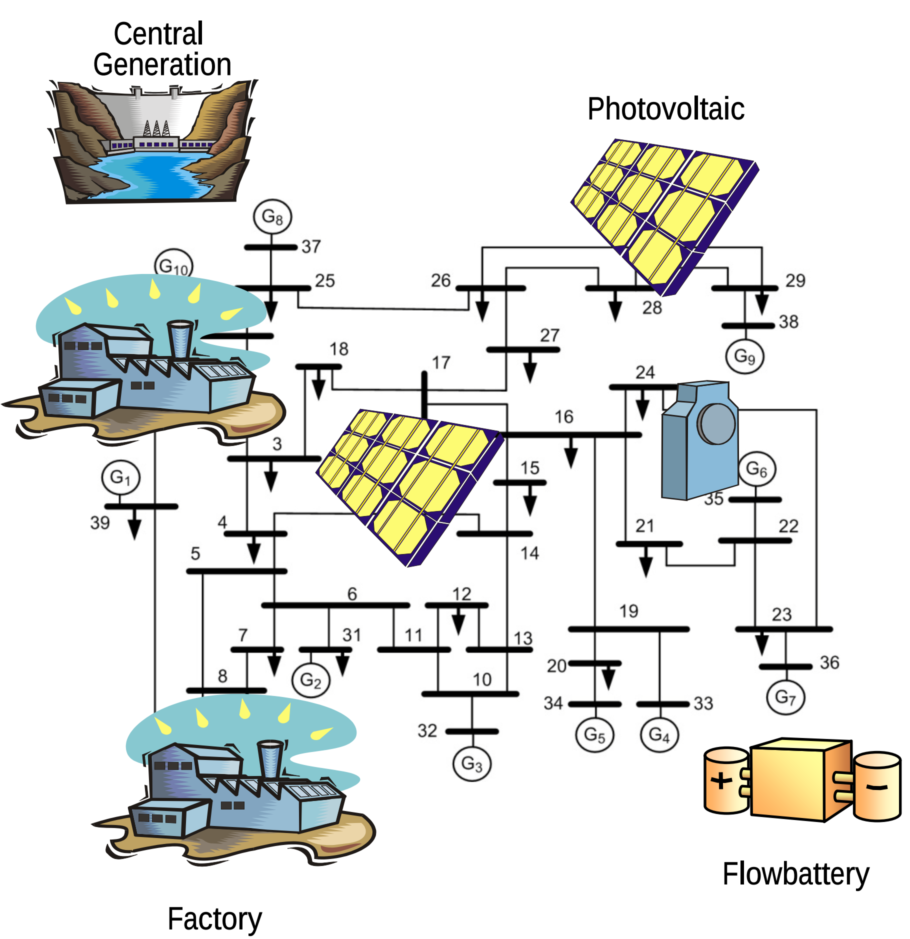




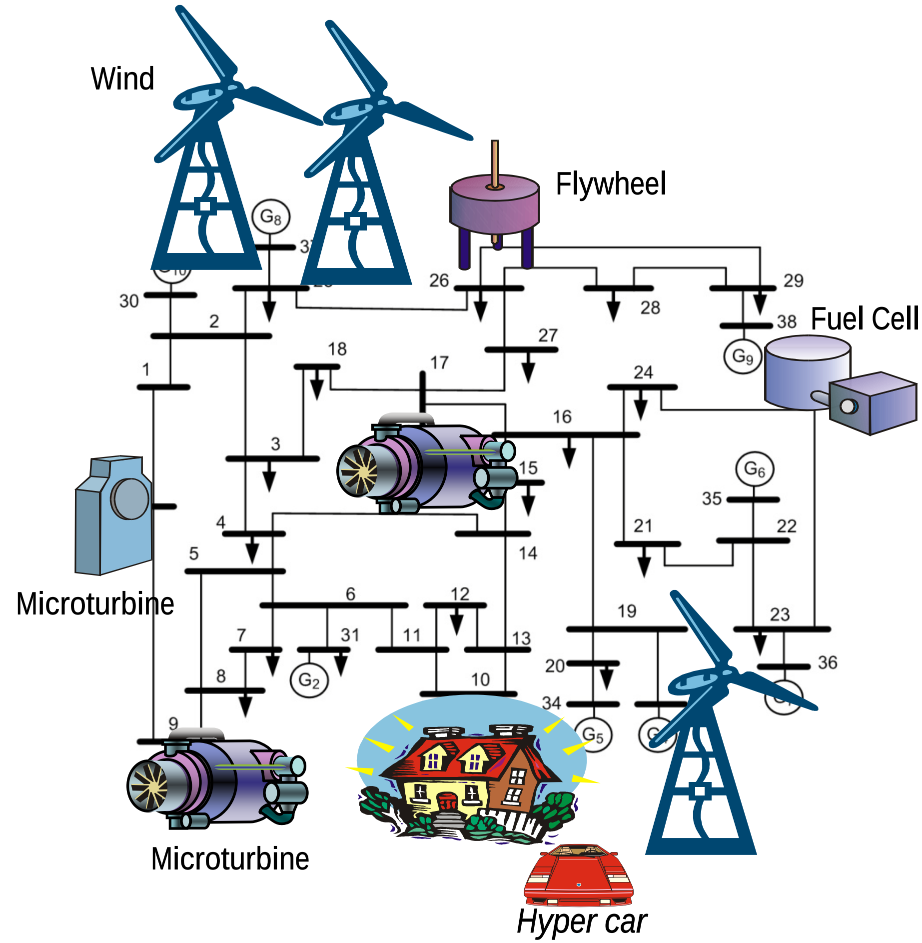
INCREASED UNCERTAINTIES

TIGHT COUPLING ECONOMY (Markets) AND PHYSICS + RT CONTROL

In operation and control of future power systems, we will be forced to rely much more on holistic scientific solutions and much less on experience which will be both scarce and cryptic (unclear how to exploit).

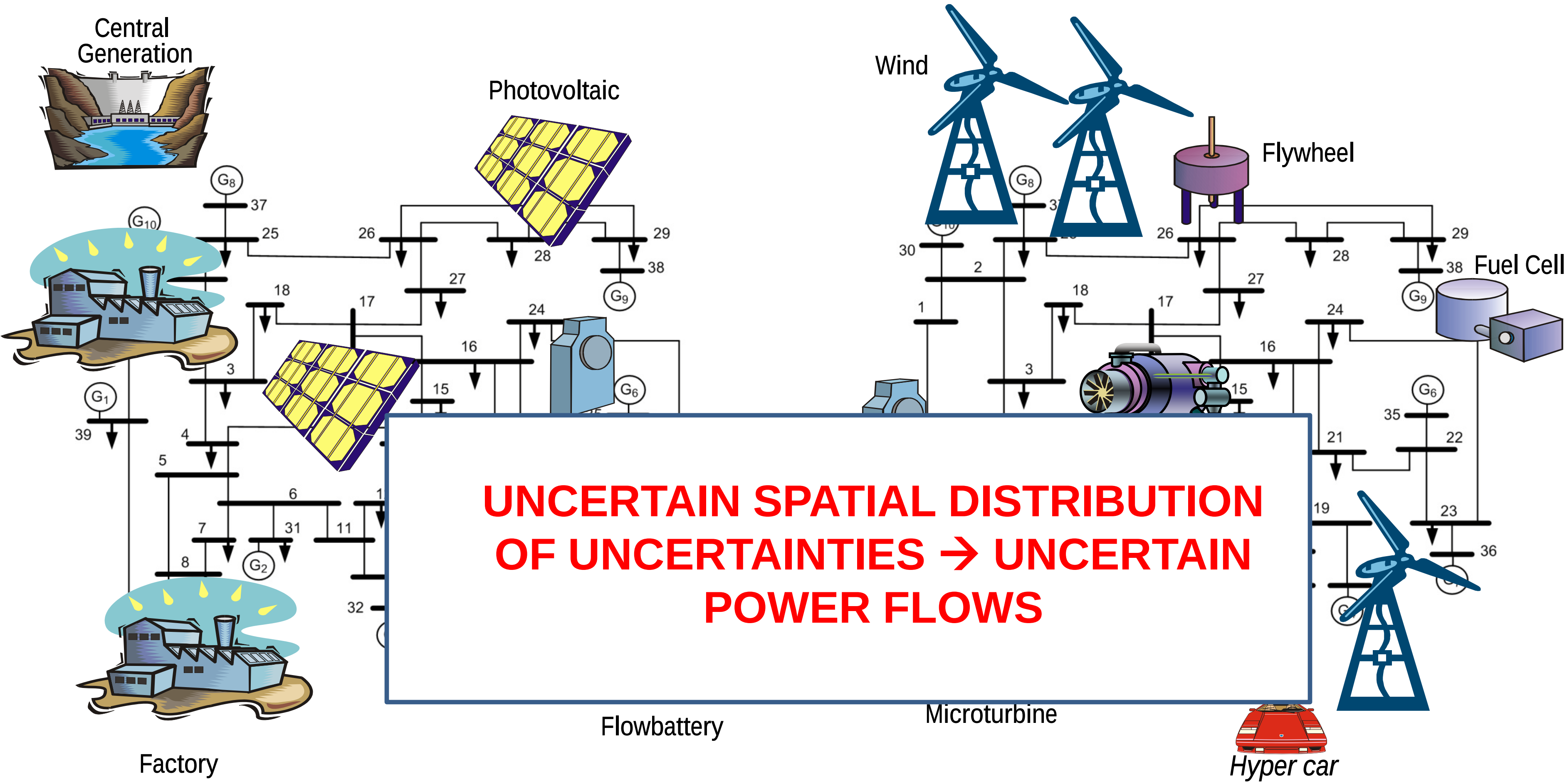


12:00 h



19:00 h

In operation and control of future power systems, we will be forced to rely much more on holistic scientific solutions and much less on experience which will be both scarce and cryptic (unclear how to exploit).

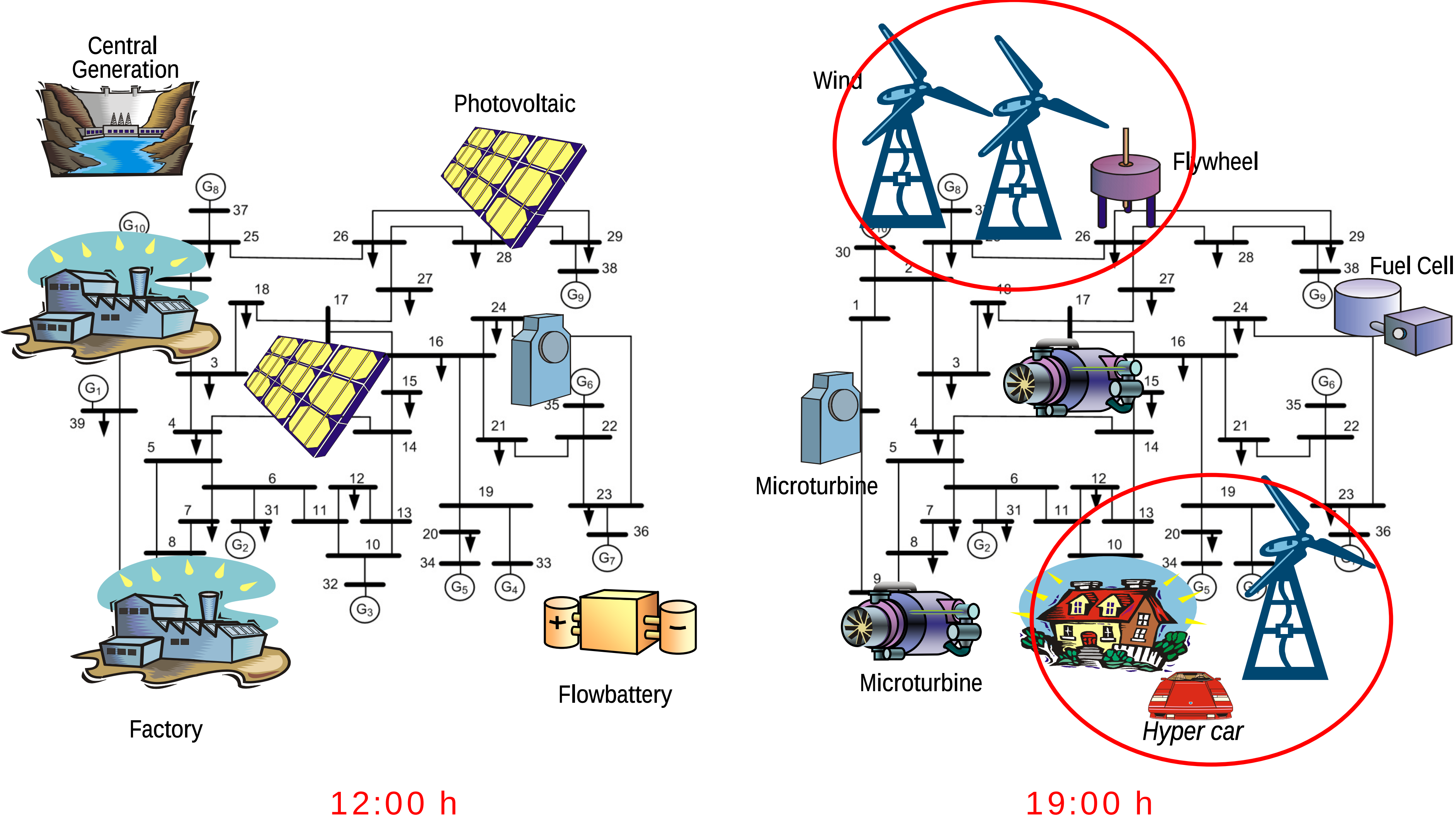


UNCERTAIN SPATIAL DISTRIBUTION OF UNCERTAINTIES → UNCERTAIN POWER FLOWS

12:00 h

19:00 h

In operation and control of future power systems, we will be forced to rely much more on holistic scientific solutions and much less on experience which will be both scarce and cryptic (unclear how to exploit).



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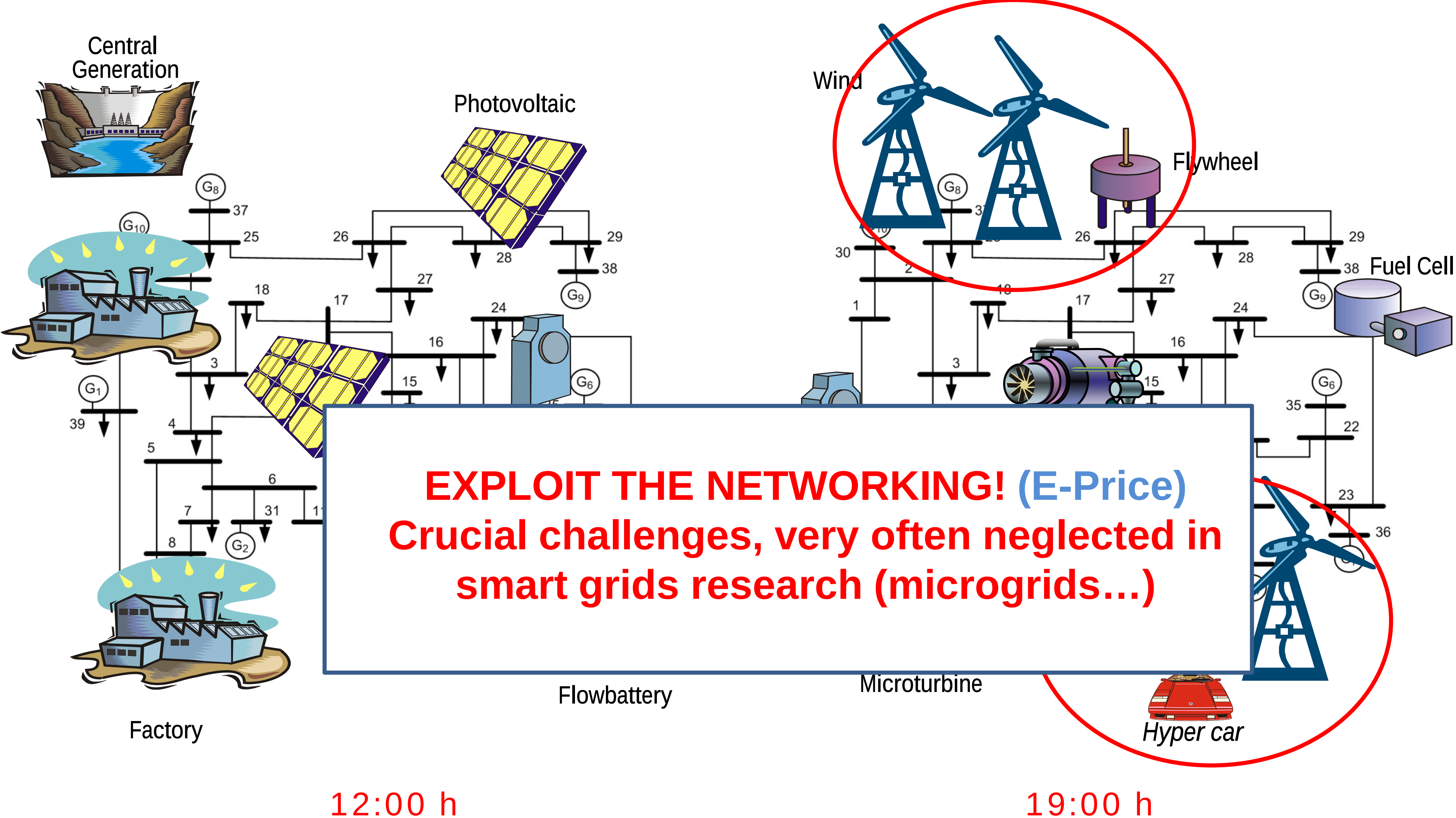


EXPLOIT THE NETWORKING! (E-Price)
Crucial challenges, very often neglected in smart grids research (microgrids…)

In operation and control of future power systems, we will be forced to rely much more on holistic scientific solutions and much less on experience which will be both scarce and cryptic (unclear how to exploit).

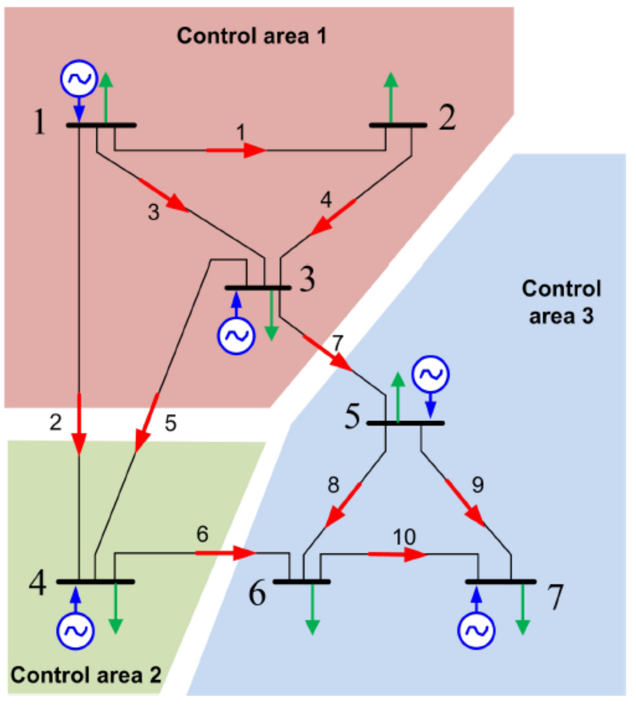
More on current system inefficiencies

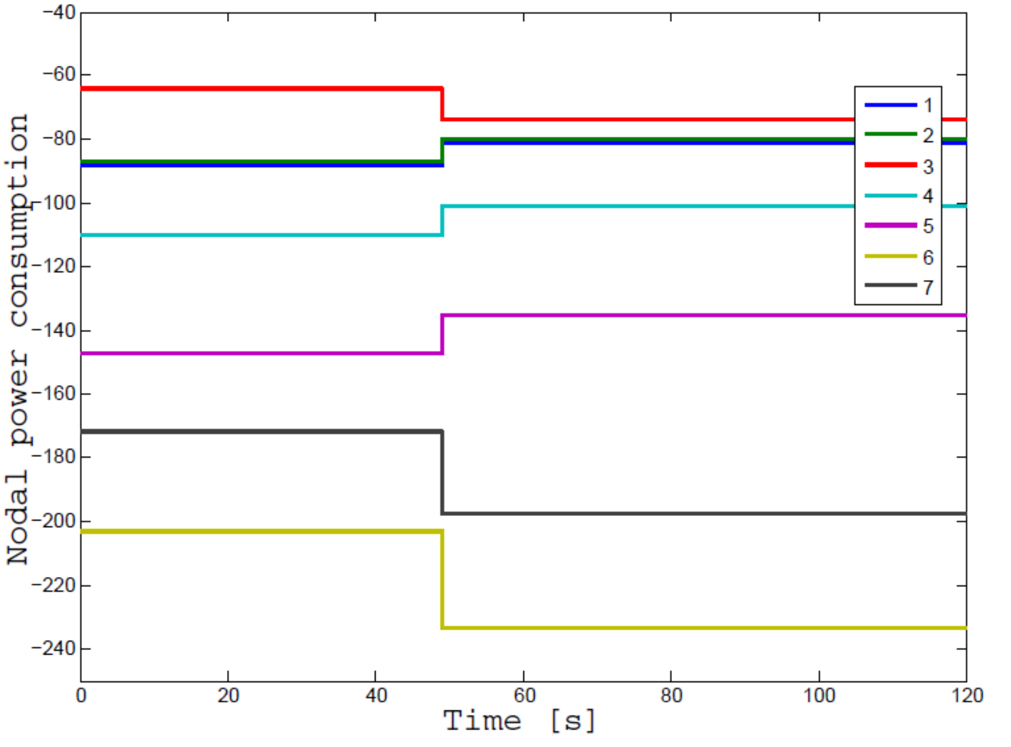
- **Inefficient use of transmission network capacity**
  - Too conservative (TSO's further limit the exchange transfers to ensure internal control area feasibility)
  - No guarantees that there will be no singe line overload (also during AS provision)

- **Lack of system-wide information sharing and coordination**
  - Market signals do not adequately reflect the overall system state
  - Potential of available ICT infrastructure not exploited
  - "fixing" the above → get the right signals for needed investments

- **Ad-hoc, (limited) simulations and experience based solutions**
  - Unreliable, nonscalable
  - Experience in future: cryptic

Example





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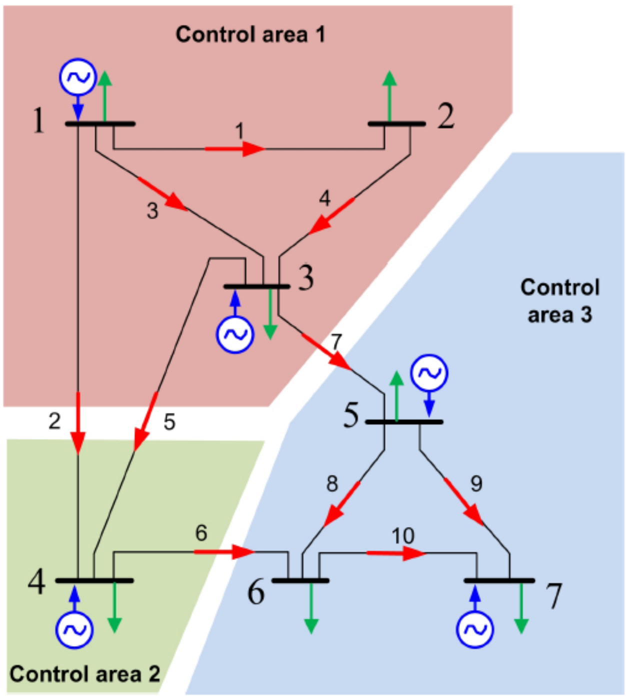
Example


Control area 1
Control area 2
Control area 3
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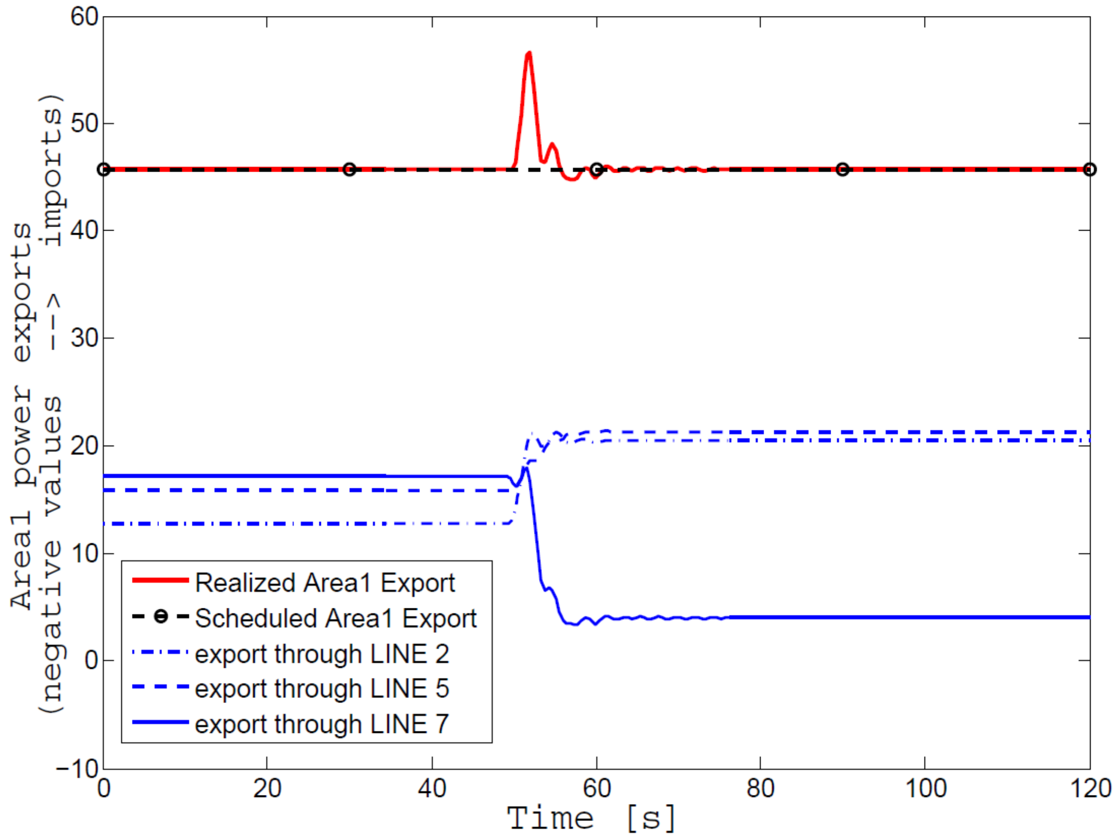
Area1 power exports --> imports
(negative values
Time [s]
Realized Area1 Export
Scheduled Area1 Export
export through LINE 2
export through LINE 5
export through LINE 7
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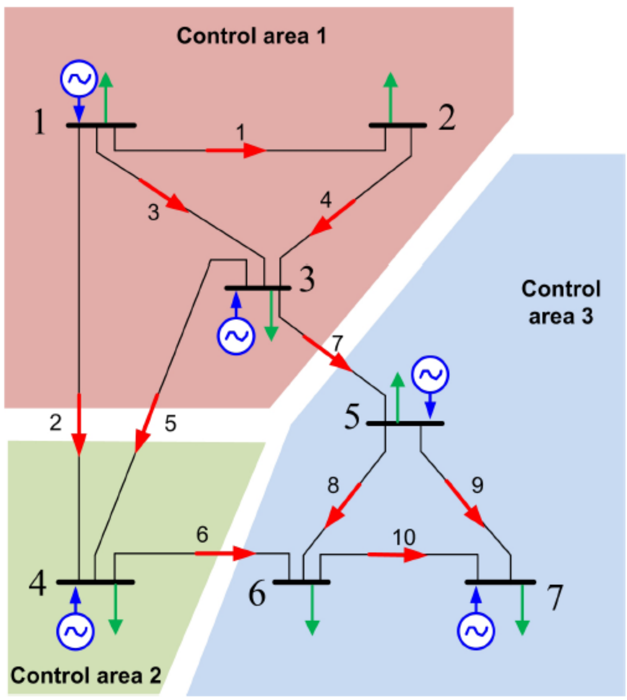
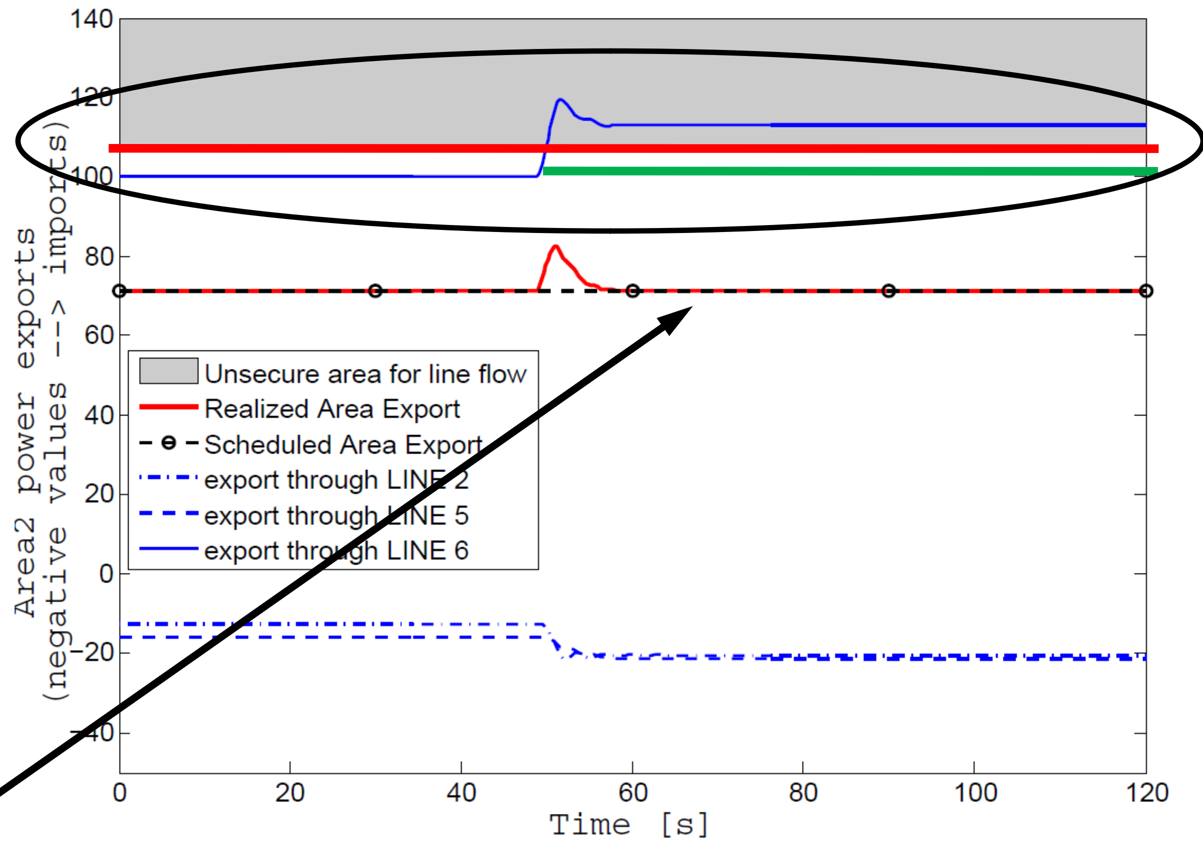
10
0
−10
0
20
40
60
80
100
120

Example





In current system, reliability is accounted for in "aggregated" form here

RELIABILITY MARGIN

Size of reliability margin: reliability vs. efficiency trade-off
Currently: no guarantees overloads will not happen

Economically optimal working point is often on the border of feasible region

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E-Price scientific approach: optimization and control

Economical efficiency subject to Global energy balance + Transmission security constraints

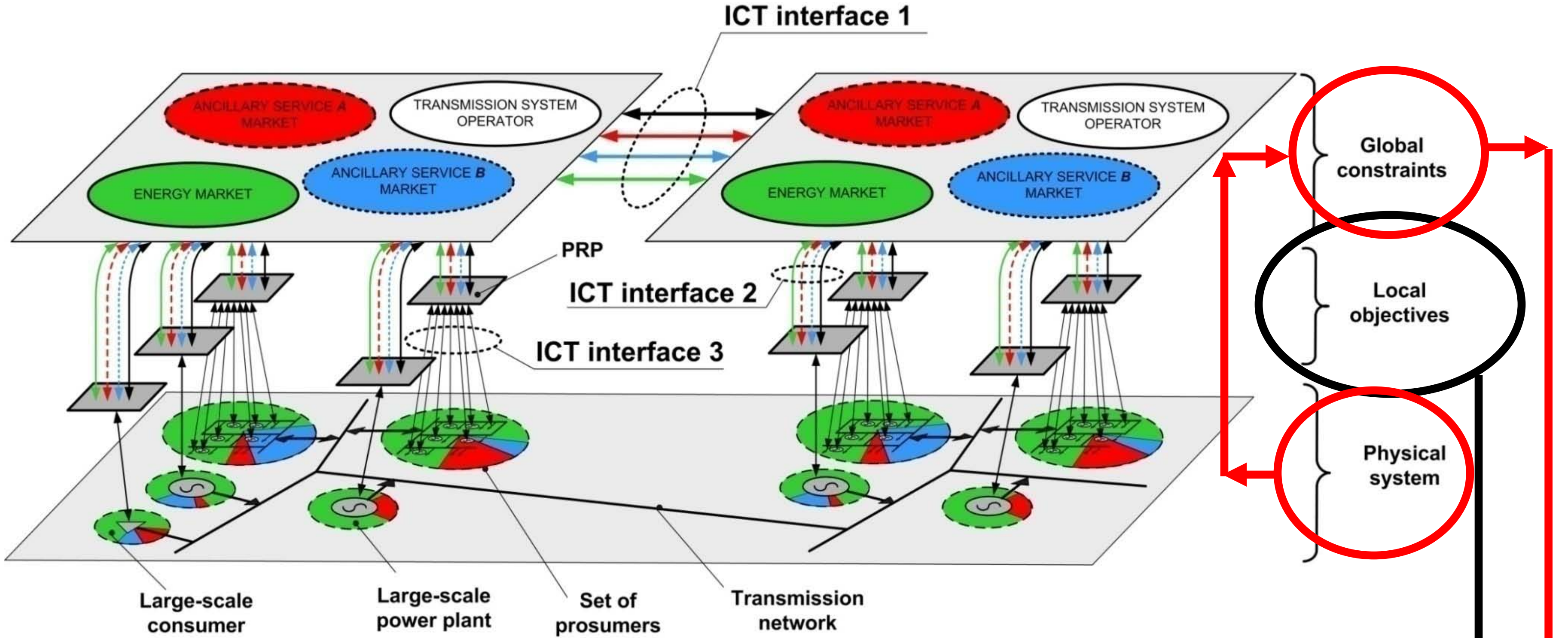
Economical efficiency subject to Accumulation of sufficient amount of AS + Security constraints

Economical and dynamical efficiency subject to Global power balance + Robust stability

ALL PROBLEMS: *structured*, time varying optimization problems

SOLUTIONS:
- Not only algorithms that give “solution” (as desired output), but:
- efficient, robust (optimally account for trade-offs!), scalable and flexible control and operational *architecture* (*who does what?, how are they related?*)

Prices and ICT: protocols and interfaces to master complexity



Global objectives = Sum of local objectives

Coupling constraints

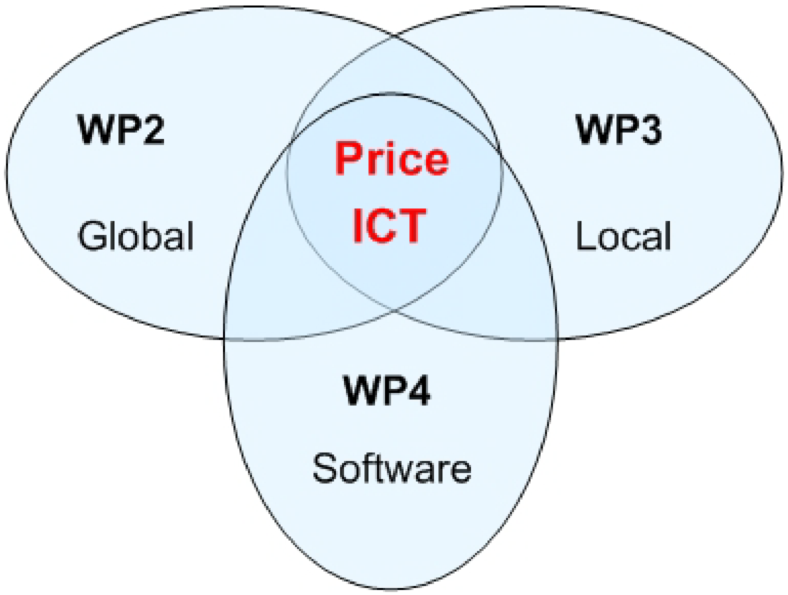
Price-based solutions = decomposition, coordination

E-Price

Prices: link local and global (supported by ICT, give incentives to local objectives to satisfy global constraints; e.g. balance, tranmission systems, stability)

Prices: asigned to and "guard" constraints

Prices: link relability and economy



Architecture for decentralized (efficient, scalable, flexible) operation:

When all parties try to achieve their own goals, the overall objectives are achieved and global constraints are satisfied

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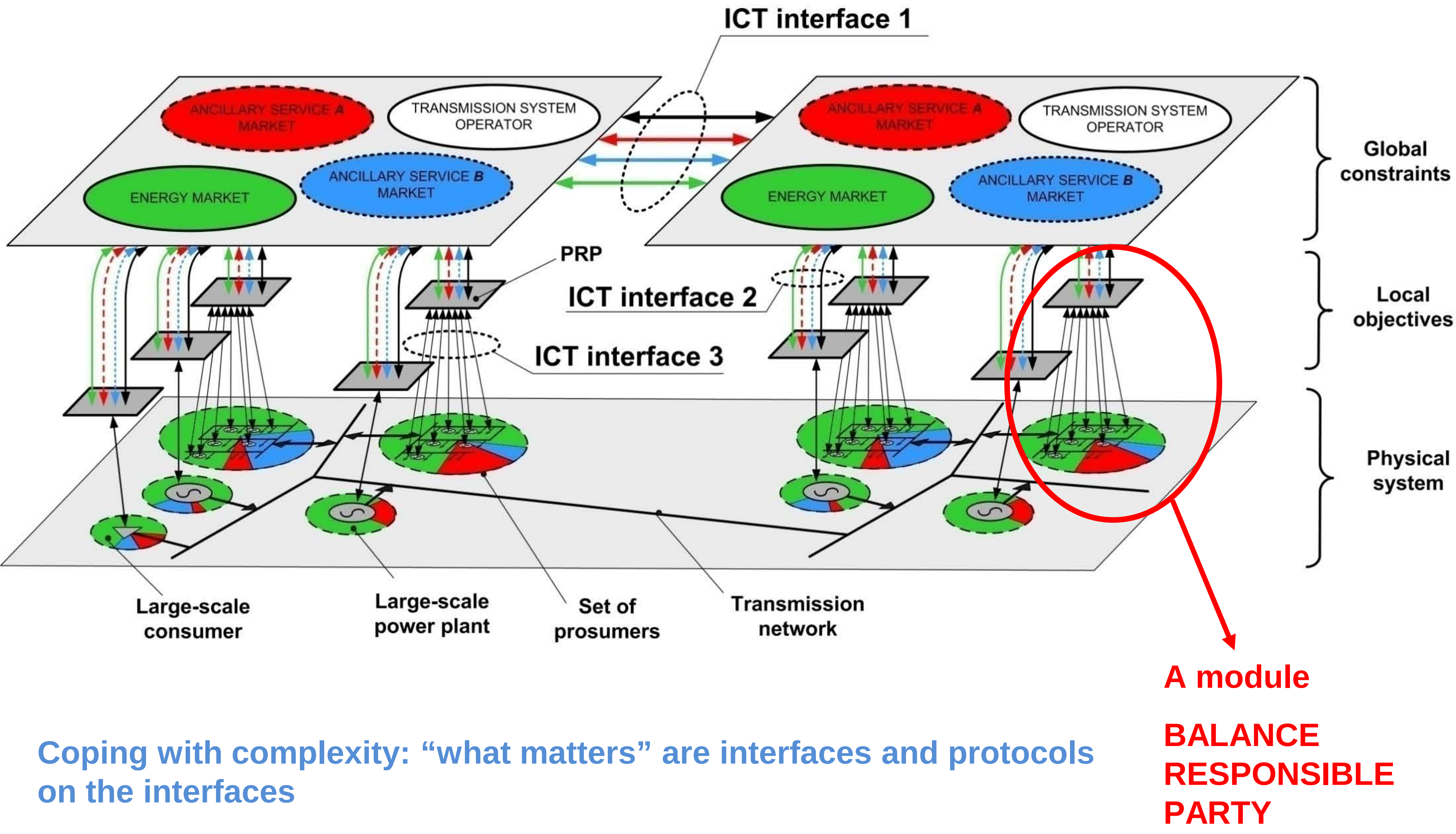
Prices and ICT: protocols and interfaces to master complexity



Coping with complexity: "what matters" are interfaces and protocols on the interfaces

Heterogeneity, local "issues", … are all hidden behind the interface.

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Summary of some contributions
Beyond state-of-the-art

BRP:

1. Optimal bidding approaches for BRPs for both the energy and the ancillary services markets (Day ahead **DA**)
2. Optimal control approaches for BRPs in real time (hierarchical MPC) (Real time **RT**)
3. Introduction of price-elastic prosumers (**RT**)
4. Flexible schedules for robust optimal reserve provision (**DA**)
5. Optimal (hierarchical) coordination of aggregated household consumers

Summary of some contributions
Beyond state-of-the-art

MARKETS/TSO:

1. Introduction of the spatial dimension (network constraints) in ancillary services (**DA, RT**)
2. Double-sided ancillary services markets (**DA**)
3. Distributed real-time ancillary services provision schemes (control) including real-time congestion management (**RT**)
4. Receding horizon pricing
5. Robust reserve operation using affine policies (Introduction of policy-based reserves)
6. Pricing based on full AC power flow equations
7. Novel distributed real-time control solutions for power balancing (distributed MPC, dissipativity-based distributed robust controller synthsis)

Summary of some contributions
Beyond state-of-the-art

ICT / ALGORITHMS:

1. Analysis of robustness to communication delays and losses
2. Assessing ICT infrastructure for support of E-Price solutions
3. Power system communication modeling
4. Novel computationally efficient algorithmic solutions (e.g. for large scale MIP; efficient SDP-based full AS pricing algorithm)
5. Algorithms for distributed calculation of prices

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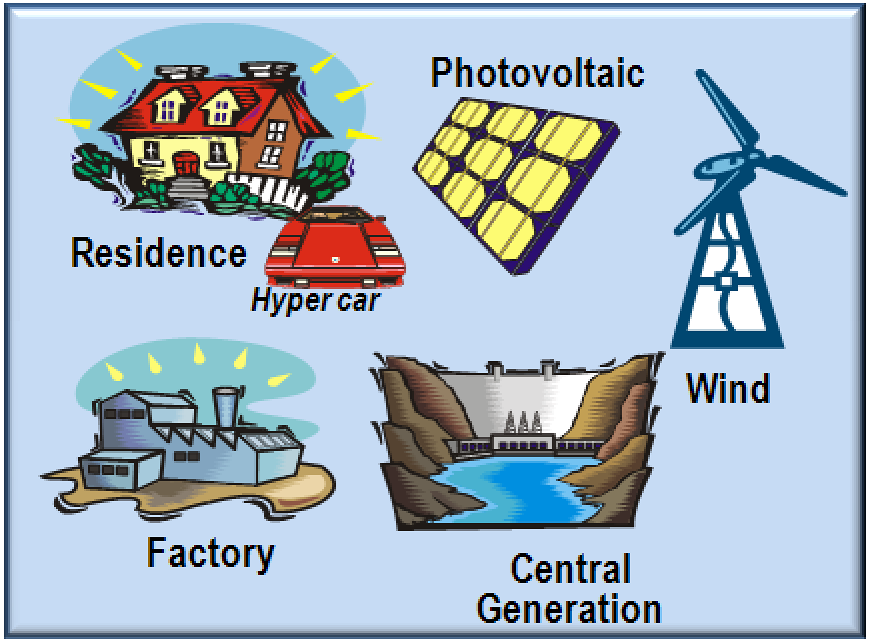
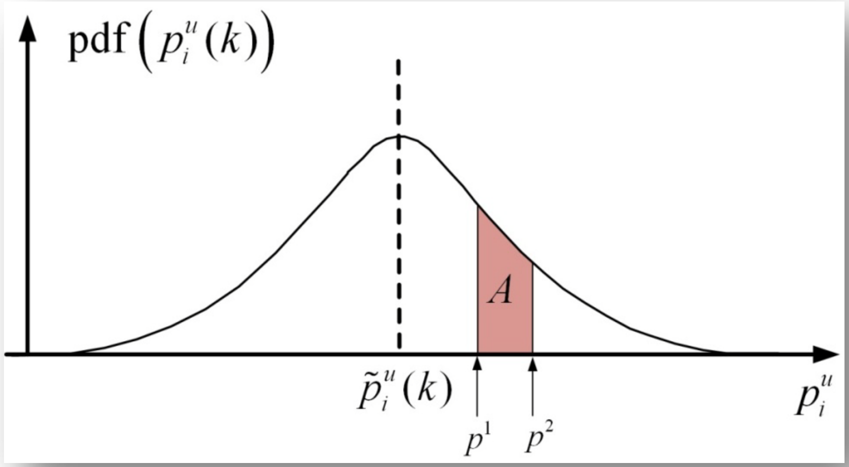
Double sided Ancillary Services (AS) markets





Double sided Ancillary Services (AS) markets

Hedging risks

BRP's options to reduce risks and maximize (probability) of economic efficiency in highly uncertain environment:

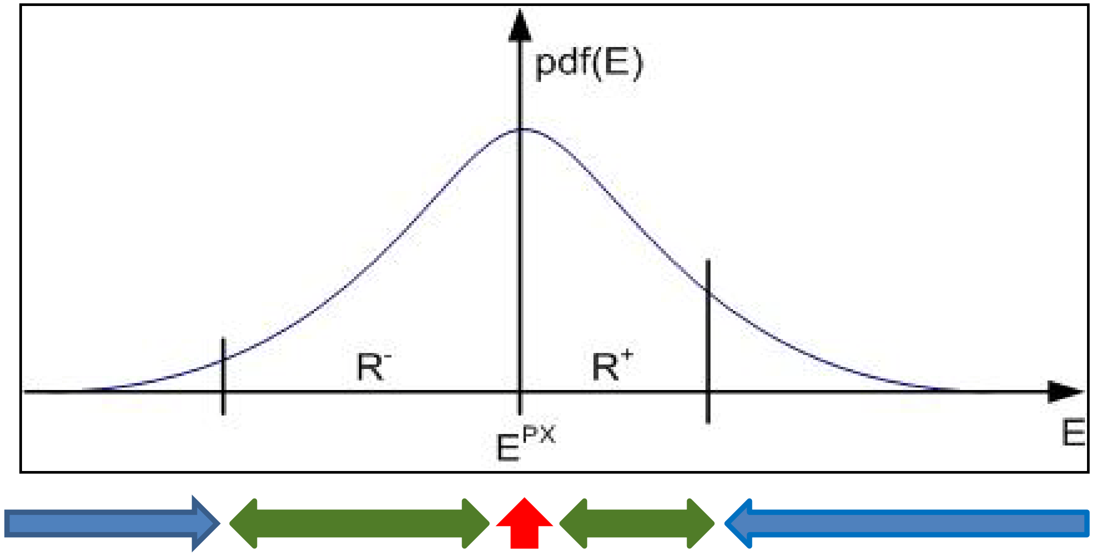
- Employ controllable prosumers in its own portfolio for keeping up the contracted prosumption level
- Aim for better predictions of uncontrollable prosumptions, energy and imbalance prices
- Buy/sell options on double-sided AS markets

BRP decision freedom

BRP has best knowledge about expected load/energy exchange.

Based on pdf (probability density function**) and expected prices:**

- **Ahead market for energy (E^{PX} [MWh])**
- **Ahead market for ancillary services (R^+, R^-, S^+, S^- [MWh])**
- **Remainder will be imbalance** *(or avoided by own actions)*



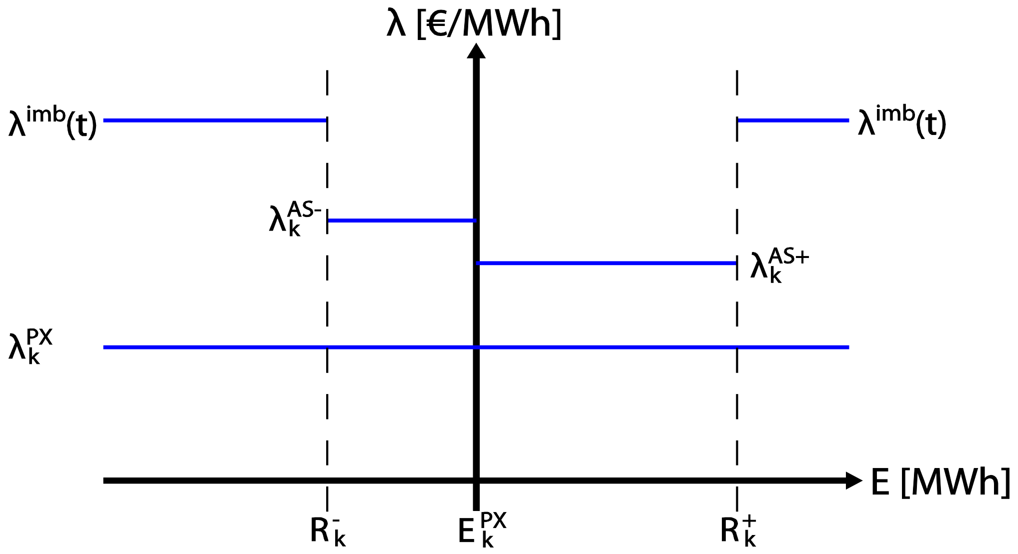
request: $R^{+/-}$

maximum surplus/deficit a BRP will try to buy on AS market

supply: $S^{+/-}$

maximum surplus/deficit a BRP will try to sell on AS market

Creating proper incentives



$$\lambda^{EX}_k < \lambda^{AS+/-}_k < E\{\lambda^i(t)\}$$

λ^{EX}_k	**price at power exchange**
$\lambda^{AS+/-}_k$	**prices from AS markets**
$\lambda^i(t)$	**real-time price for power imbalance (expected)**

Forward market: ***The risk of bidding is less or equal than the risk of not-bidding***

In real-time: ***The risk of a requested action is less or equal than the risk of a not-requested action***

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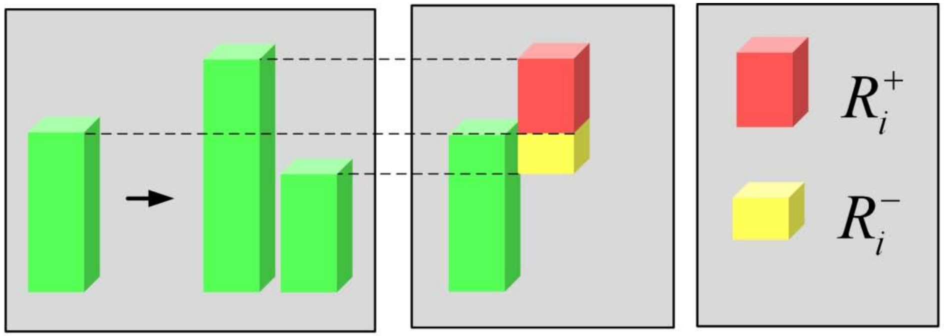
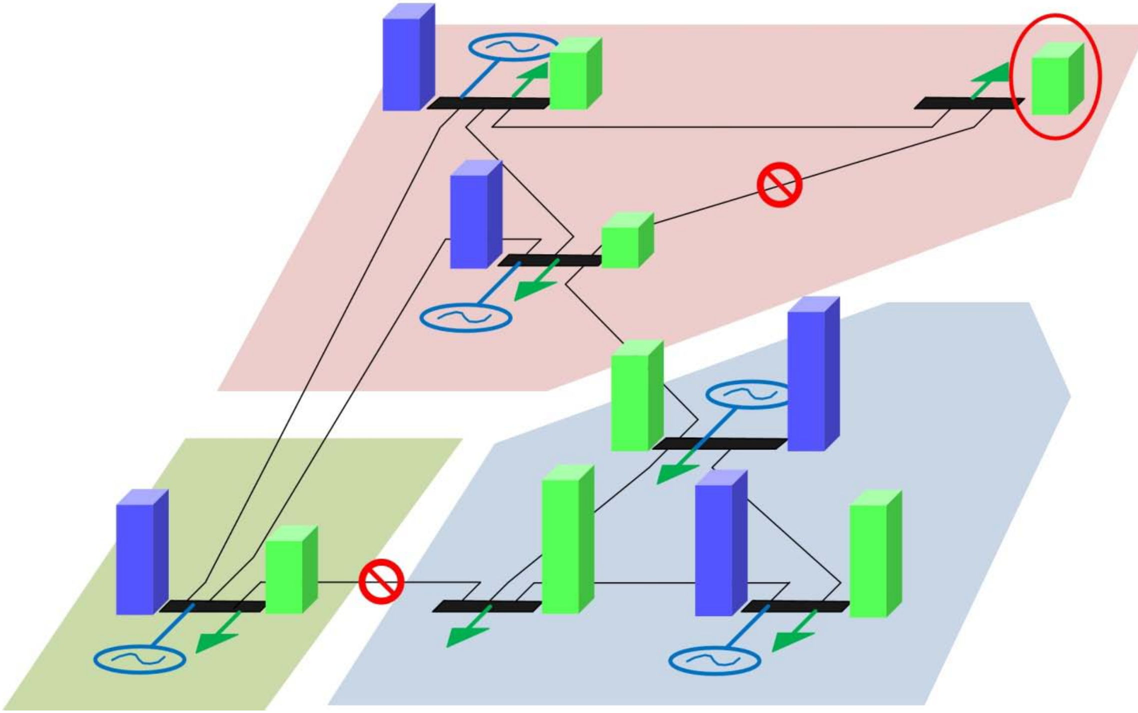
Uncertainties and ancillary services
Spatial dimension; forward time markets





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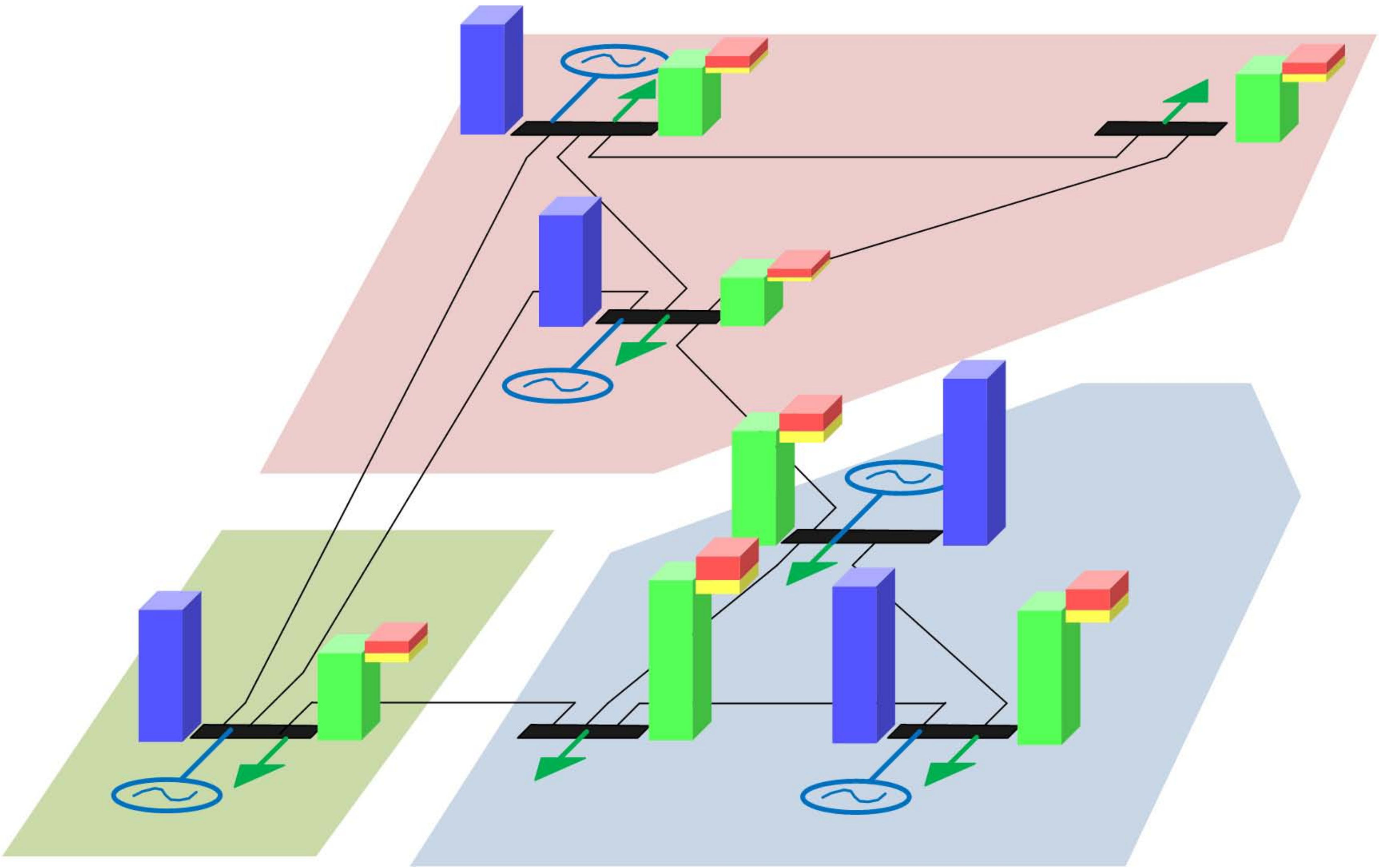
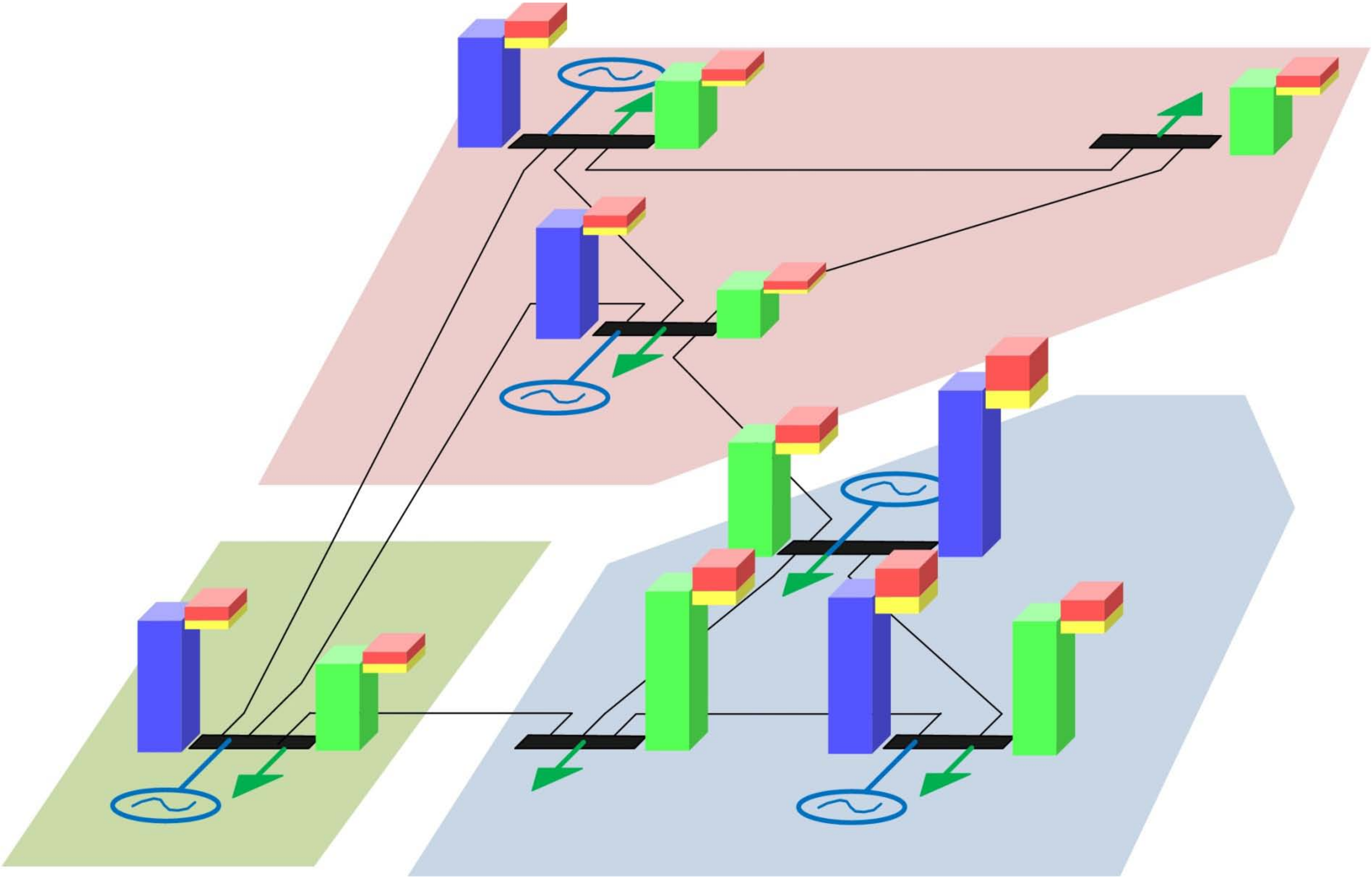
Uncertainties and ancillary services

Spatial dimension; forward time markets



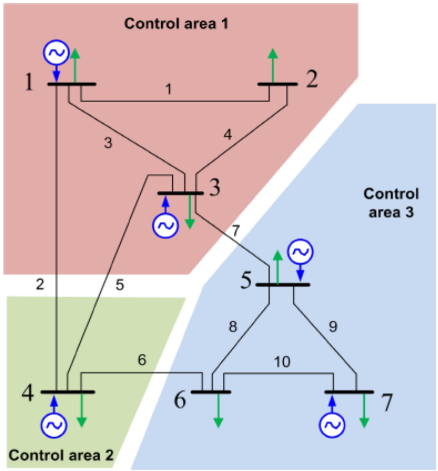
Uncertainties and ancillary services
Spatial dimension; forward time markets



More on current situation (AS)

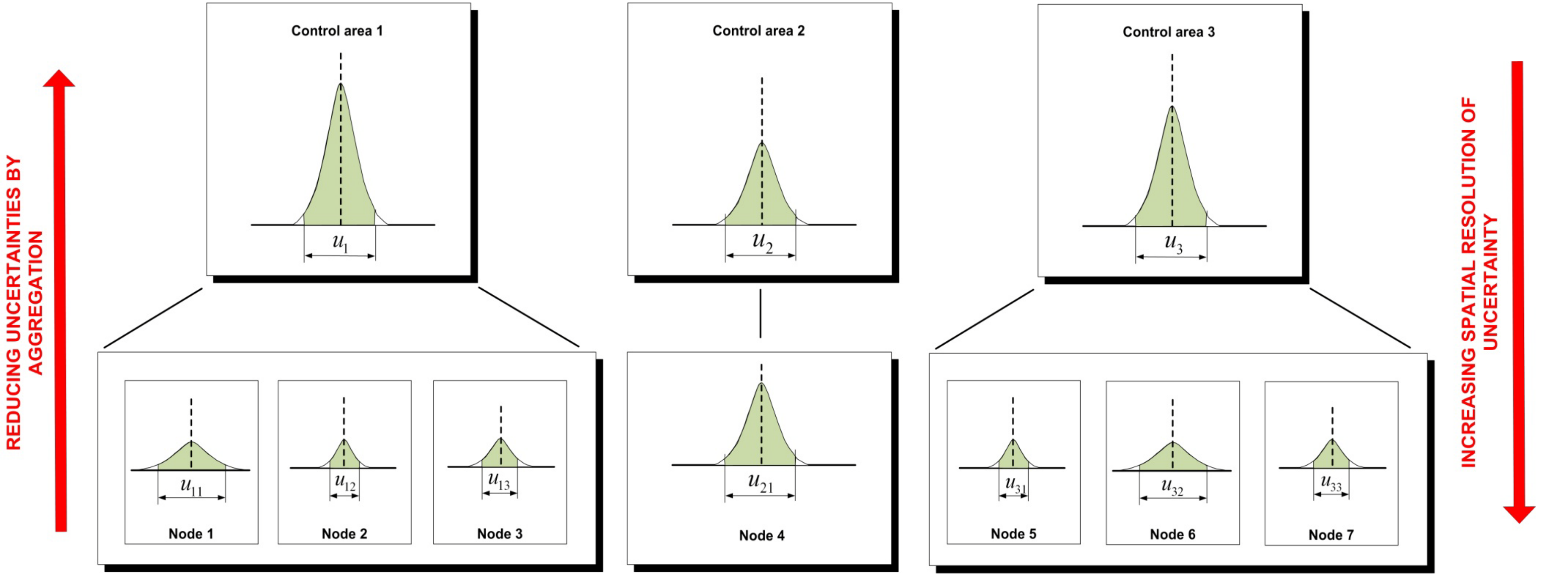
- **No efficient framework for BRPs to hedge their risks**
- **No framework to exploit existing knowledge of BRP's about their own uncertainties for global level control (TSO)**
- **No framework for BRP's to expose their uncertainty levels to TSO's**

Spatial resolution of uncertainty knowledge

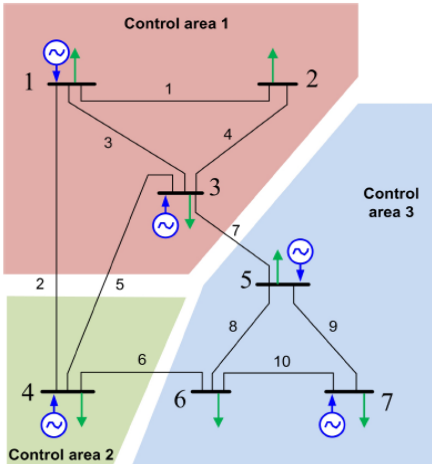


Spatial distribution of uncertainties is crucial in defining uncertainties in power flows

Double sided AS markets provide TSO's with uncertainty knowledge of high spatial resolution



Spatial resolution of uncertainty knowledge



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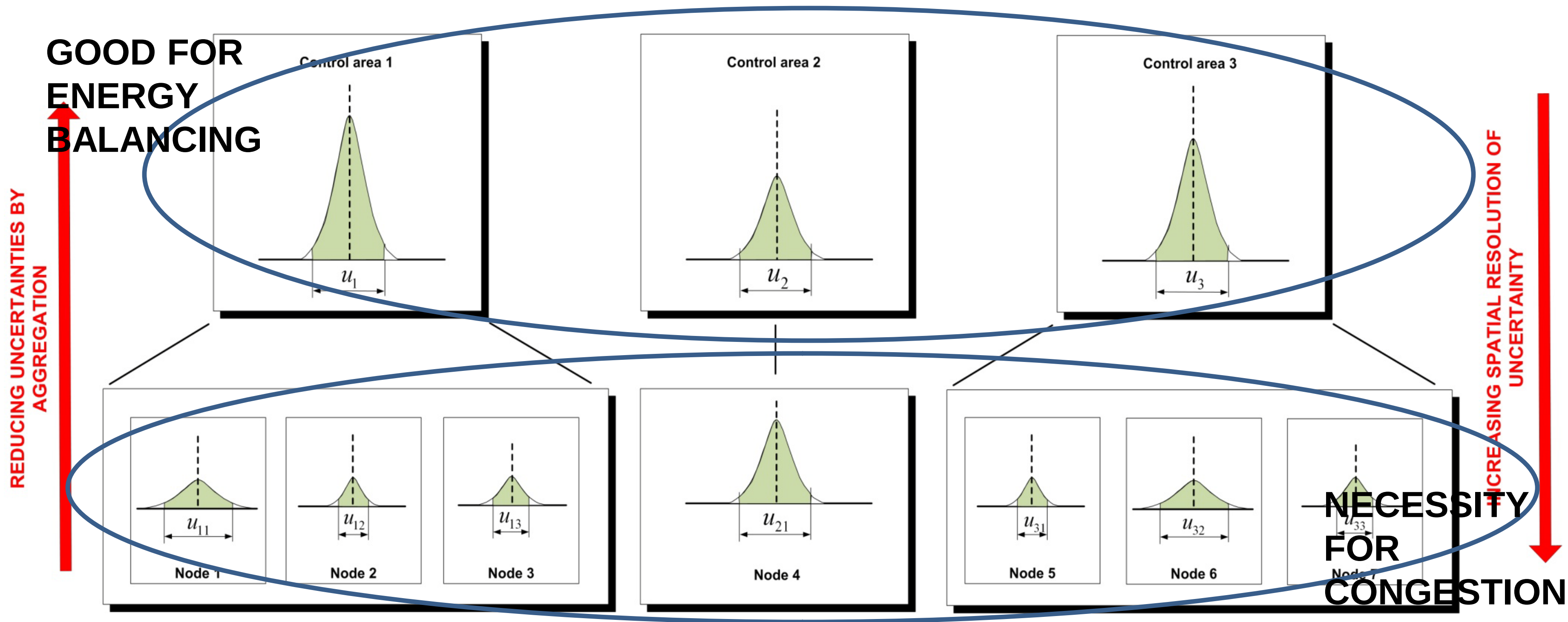


Proposed solutions

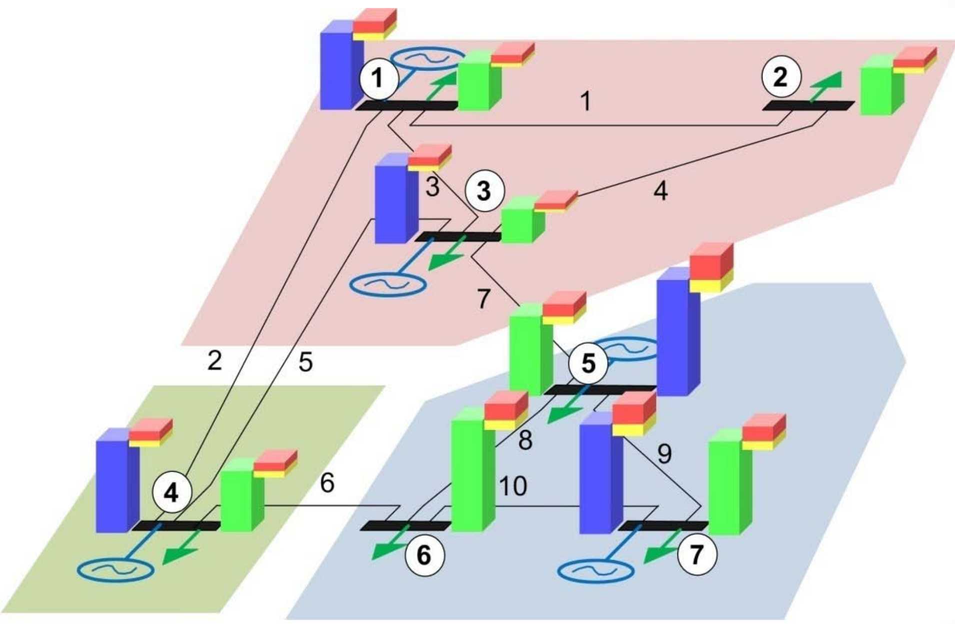
B: Network constraints at global level, introducing uniform, zonal or nodal prices for AS

B1: congestion is solved in the market,

based on robust optimization

> no congestion for any imbalance traded in the AS markt

B2: congestion is solved in real-time (imbalance pricing)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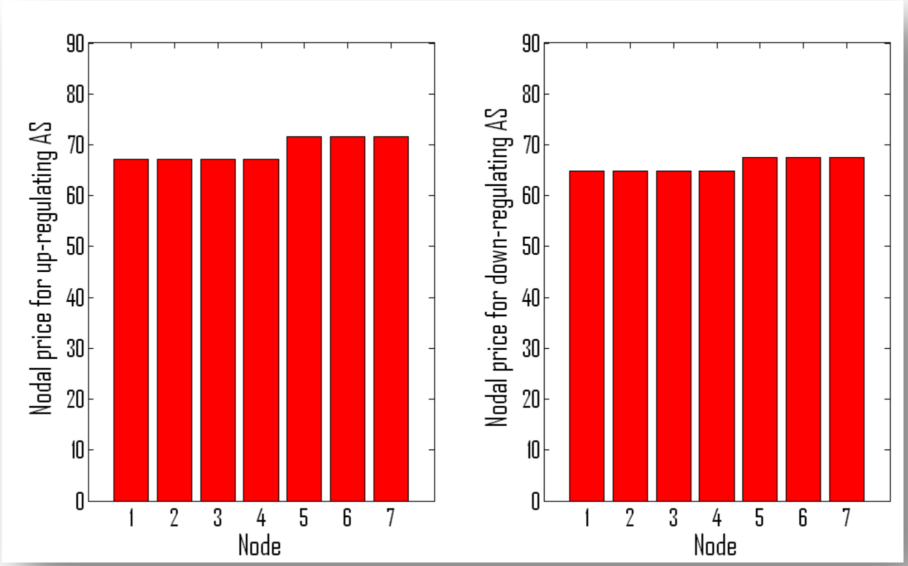
Nodal price for up-regulating AS
Nodal price for down-regulating AS
Node
Node
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70
80
90
1
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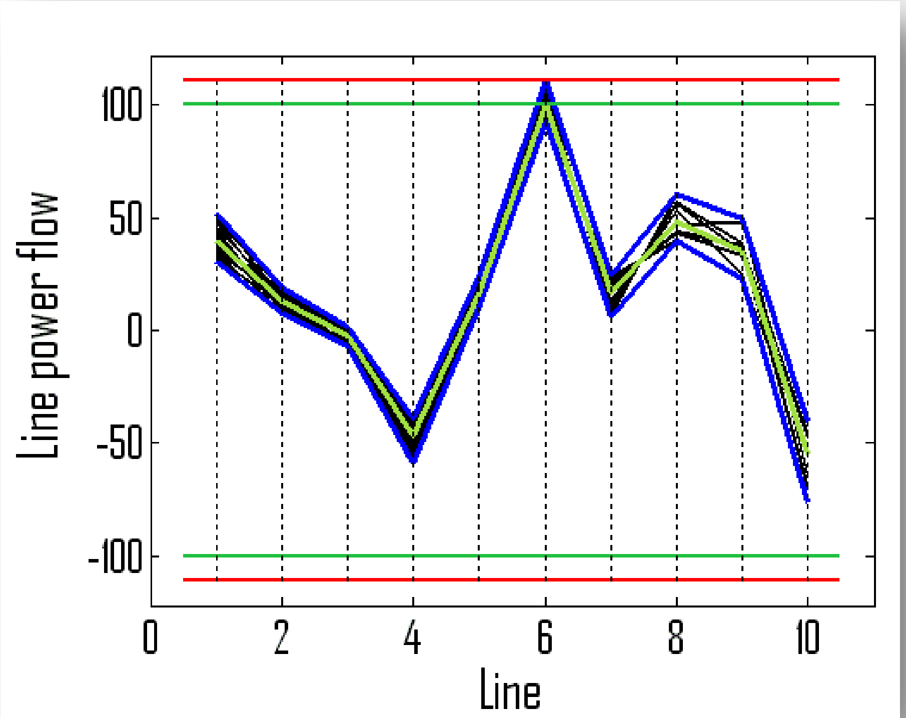
Line power flow
Line
100
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0
-50
-100
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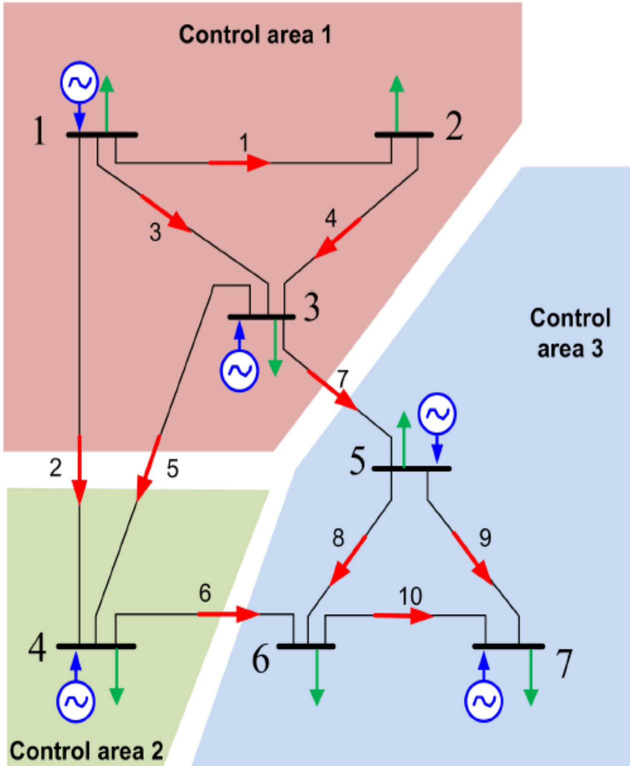
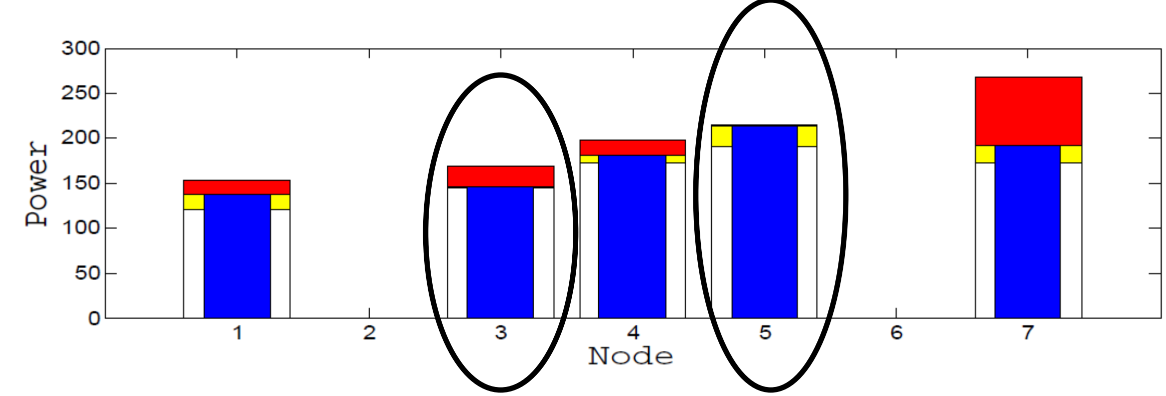
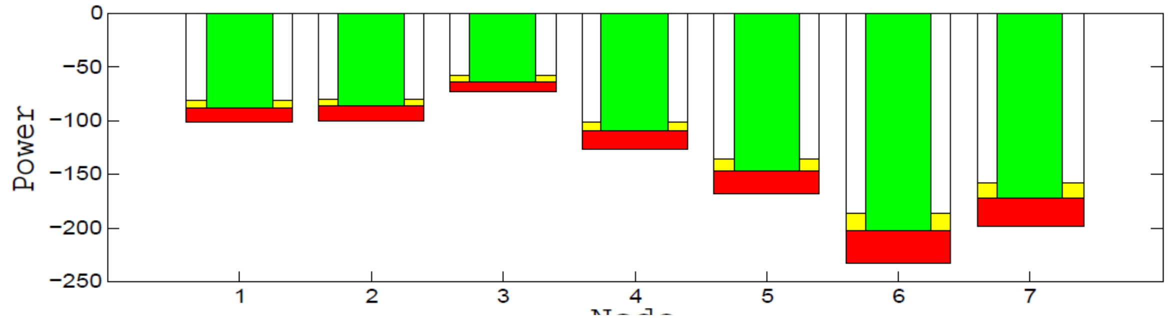
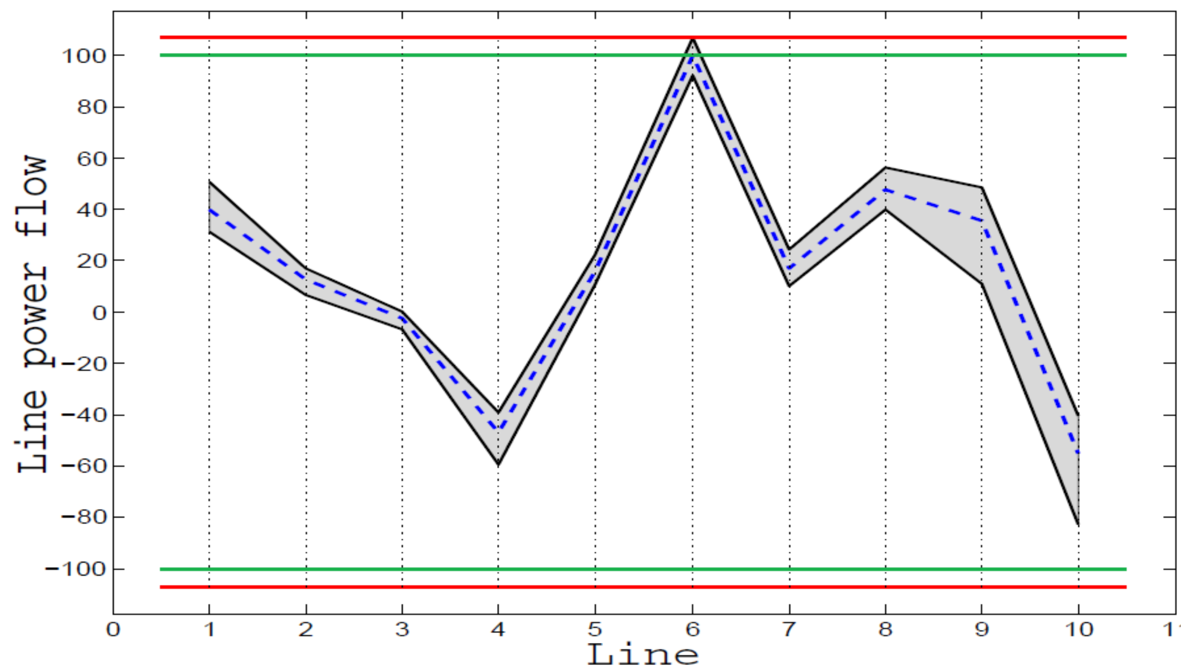






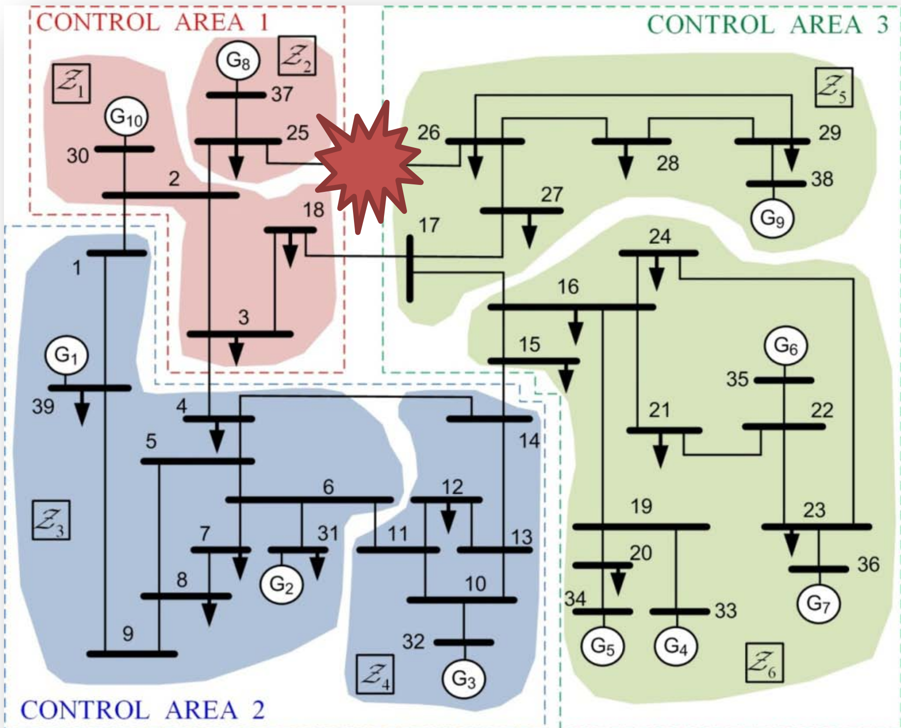


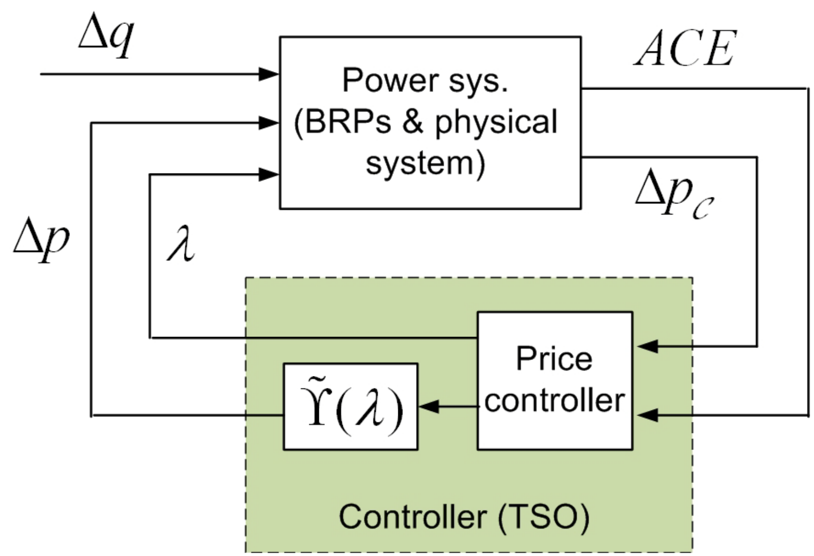
Spatial distribution of AS:
Shaping the “uncertainty tube”→

Get reliability for best costs

Possible to include optimal cooperation between control areas

Real-time zonal pricing and congestion management (real-time IMBALANCE PRICING)





IEEE New England system

- 3 control areas
- 6 zones
- 39 nodes

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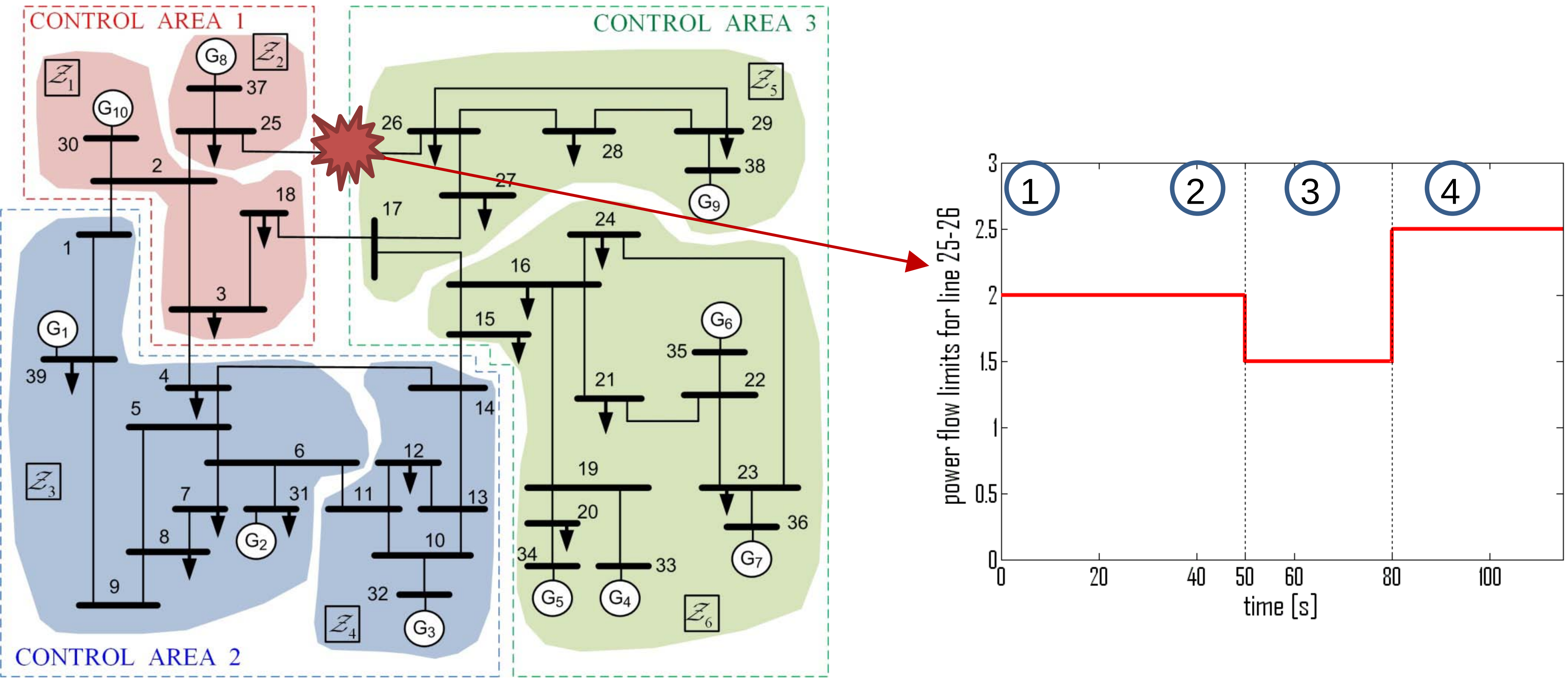
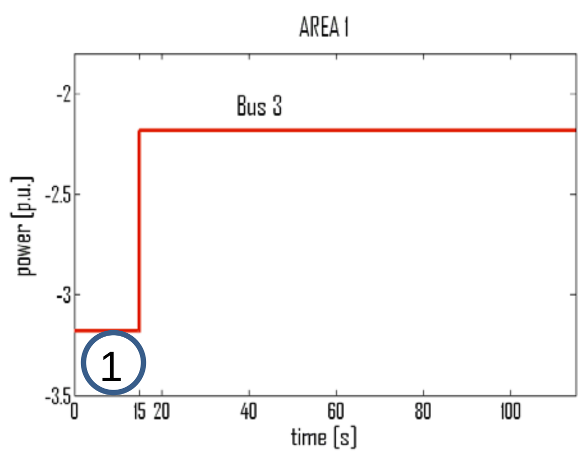
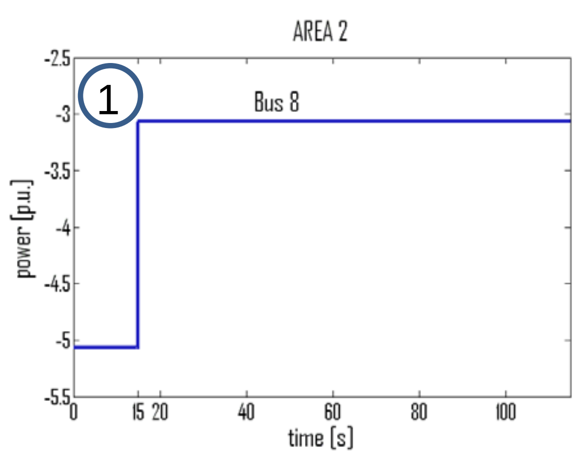
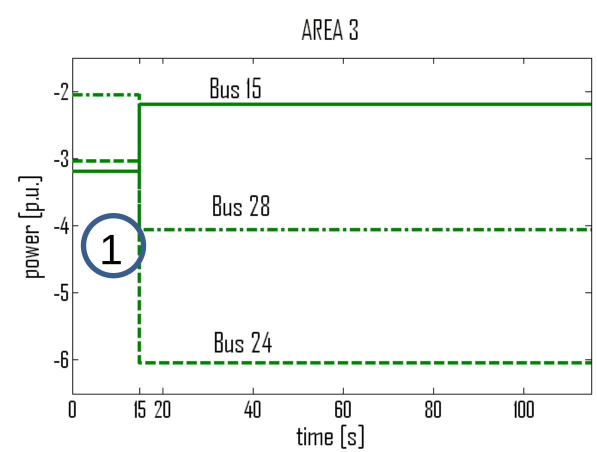
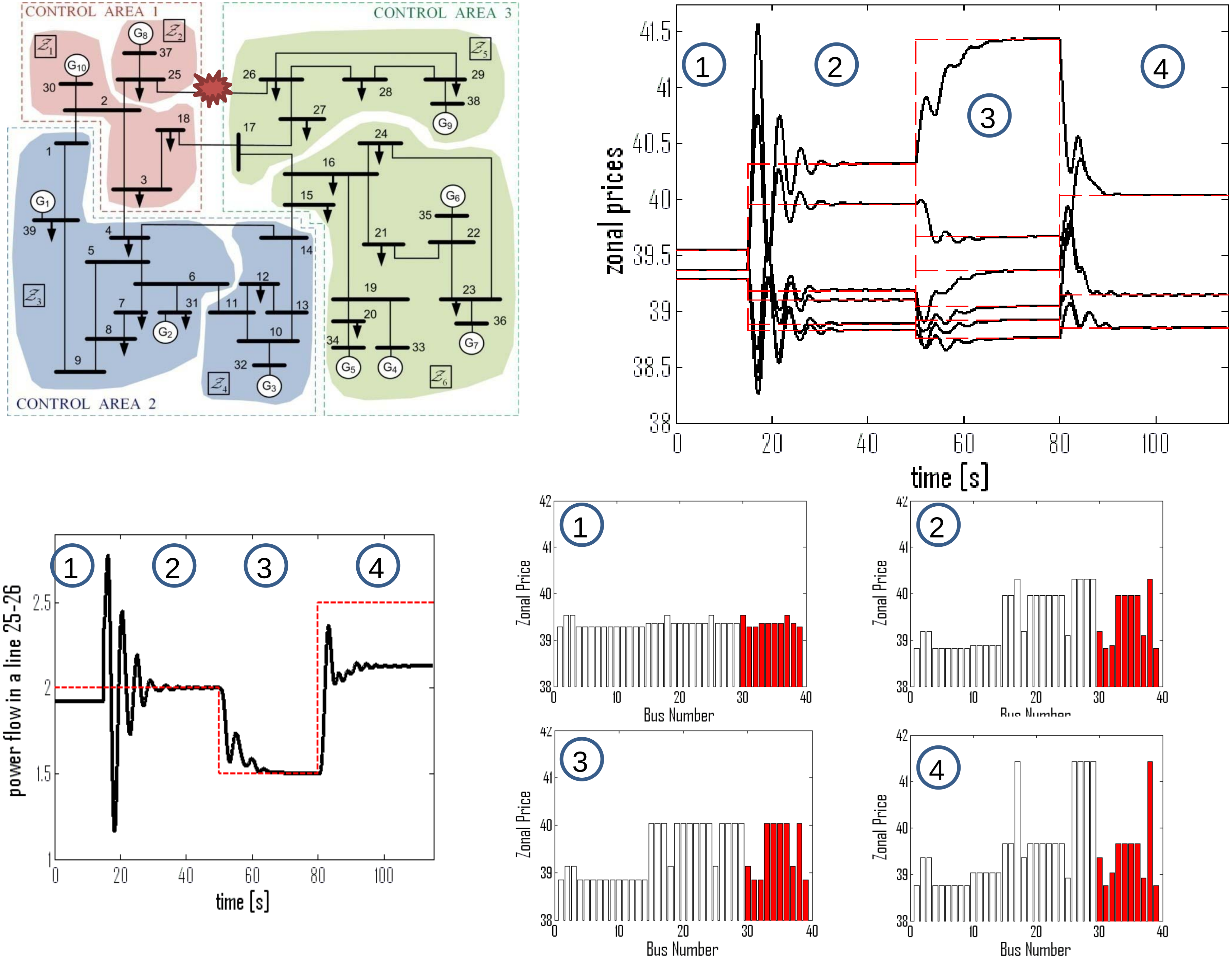
EXAMPLE


CONTROL AREA 1
CONTROL AREA 2
CONTROL AREA 3
power flow limits for line 25-26
time [s]
1
2
3
4


AREA 1
Bus 3
power [p.u.]
time [s]
1

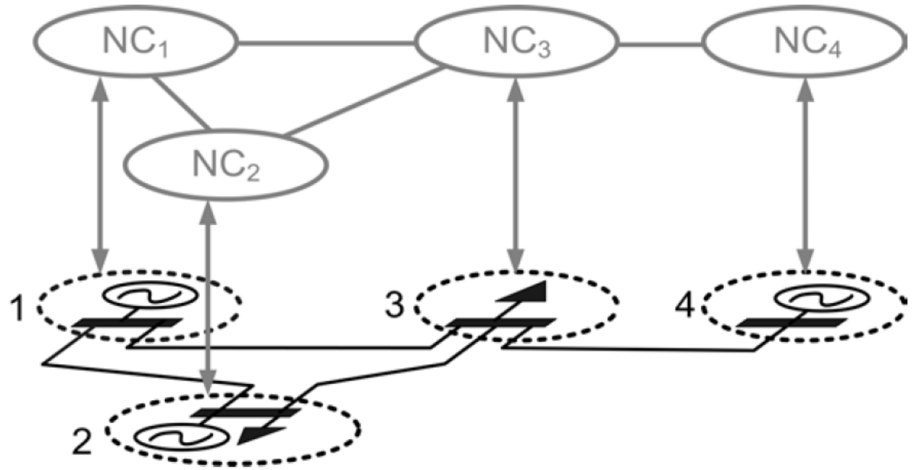

AREA 2
Bus 8
power [p.u.]
time [s]
1


AREA 3
Bus 15
Bus 28
Bus 24
power [p.u.]
time [s]
1


CONTROL AREA 1
CONTROL AREA 2
CONTROL AREA 3
zonal prices
time [s]
power flow in a line 25-26
time [s]
Zonal Price
Bus Number

Structure in power system's model

Structure in power flows → structure in relations among optimal prices



→ DISTRIBUTED Optimization and Control

Optimality with

→Flexibility
→Robustness
→Scalability

Outline

- Motivation; problems and challenges
- E-Price approach
- Overview of results
- In some more detail:
  - double sided AS markets
  - spatial dimension of energy and AS trading
- **Trade-offs (reliability, efficiency, complexity)**
- Conclusions

eprice
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THE problem at system level

reliability <> economy

TSO <> BRP

large safety margins <> small safety margins

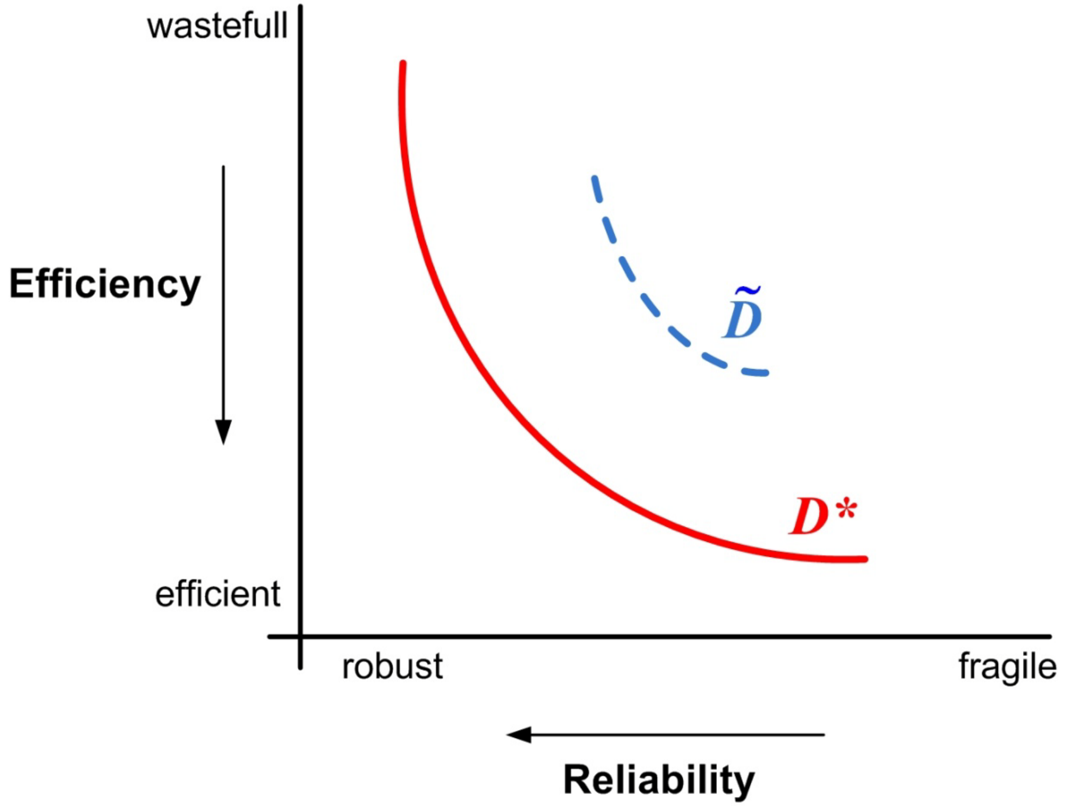
much regulation	**<>**	**few regulation**
national markets	**<>**	**one EU market**
grid constraints in market	**<>**	**grid constraints by TSO**

Trade-offs (reliability versus efficiency)

Trade-offs are inherent

Social welfare
(costs + benefits)

Dynamic
performance



Reliability margins

Proper uncertainty modeling and control design

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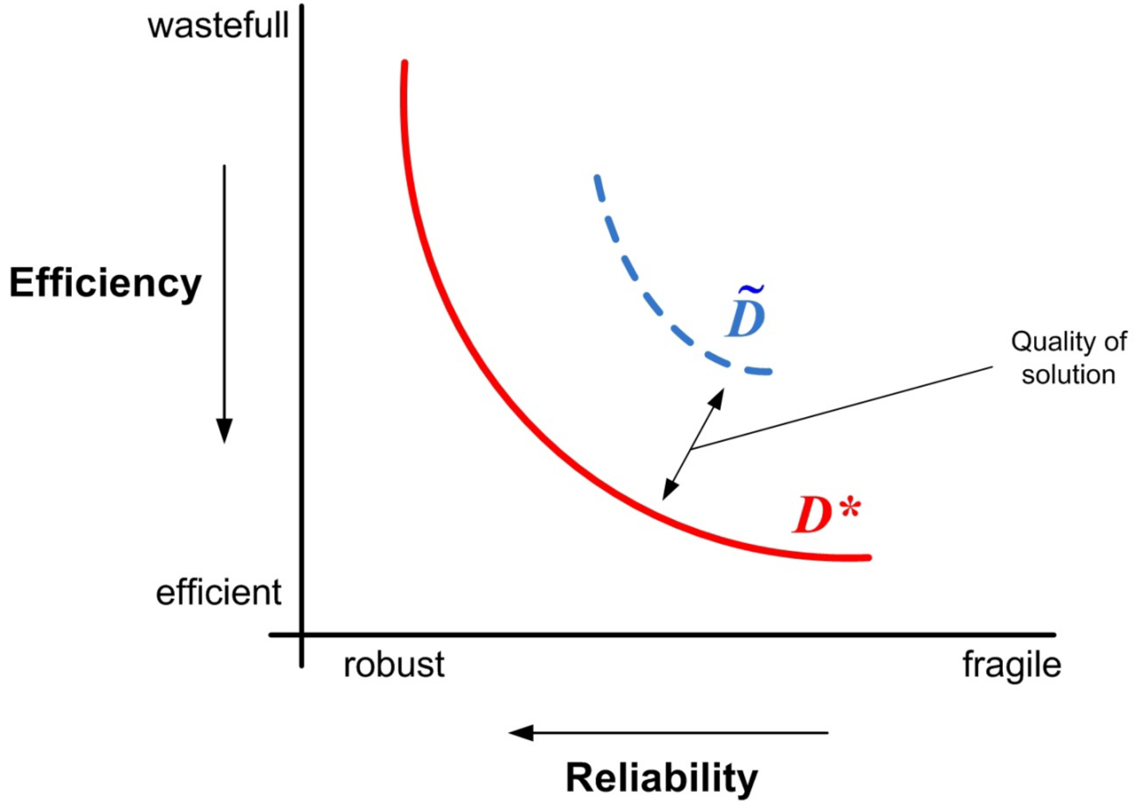
Trade-offs (reliability versus efficiency)

Trade-offs are inherent



E-Price: consider quality of solution in the sense that the obtained efficiency reliability trade-off curve (Pareto frontier) is close to the objectively achievable, inherent trade-off limits (hard limits)

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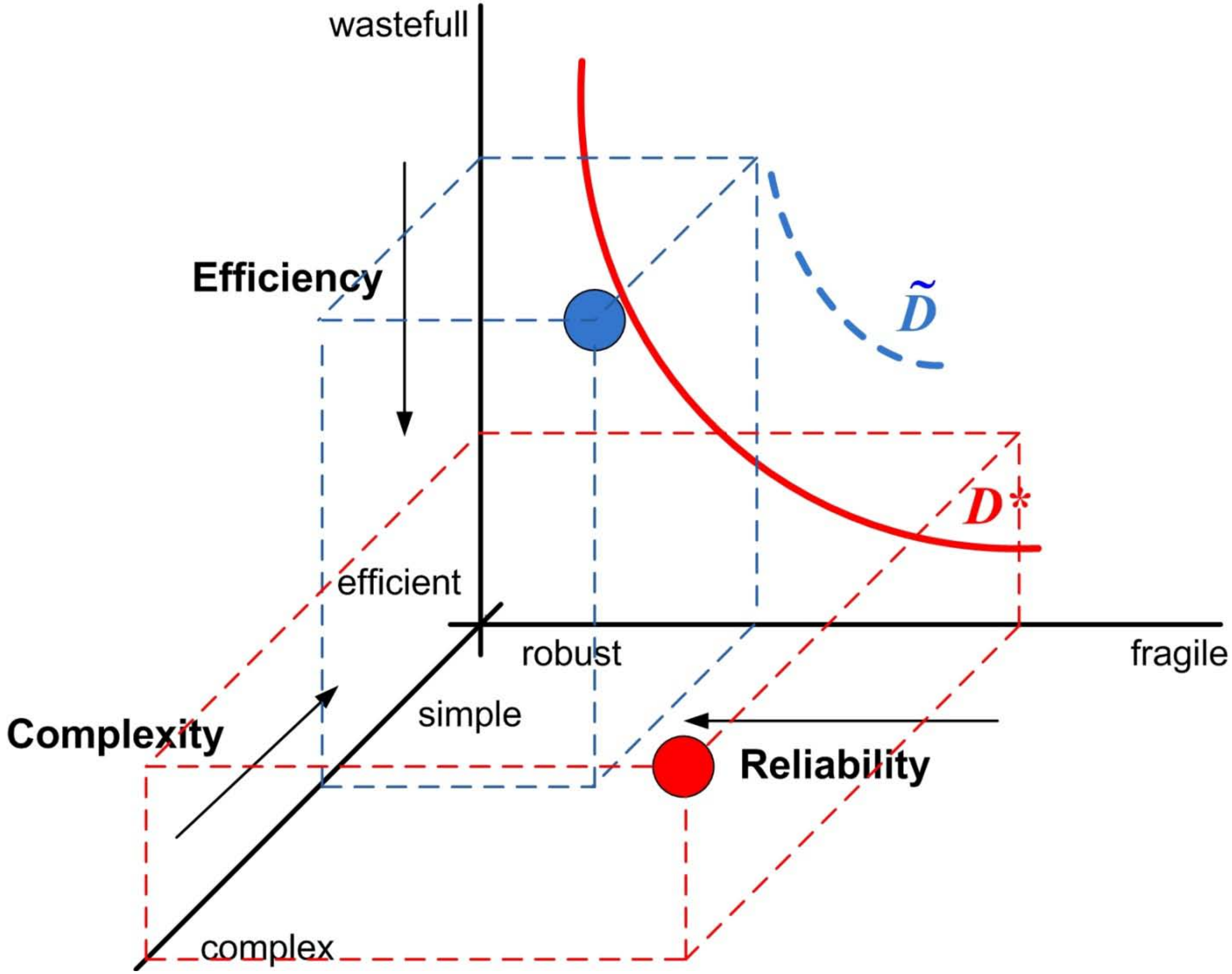
Trade-offs (reliability versus Efficiency)

Trade-offs are inherent



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Exploit the networking… and get the trade-offs right (optimization)

1 Economic efficiency	⟺	Reliability
2 Local objectives	⟺	Global objectives / constraints
3 Complexity	⟺	Scalable solutions, verifiable properties

Unifying approach to design operation/control architecture:

formulate power systems goals as optimization problems

solve problems by decomposing them

exploit (beyond) state-of-the-art control theory

- use prices and incentives
- use realistic ICT solutions

…many independently valuable results, ideas and insights along the way www.e-price-project.eu

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