A DYNAMIC FRAMEWORK FOR SMART ENERGY SYSTEMS
Opportunities & Challenges

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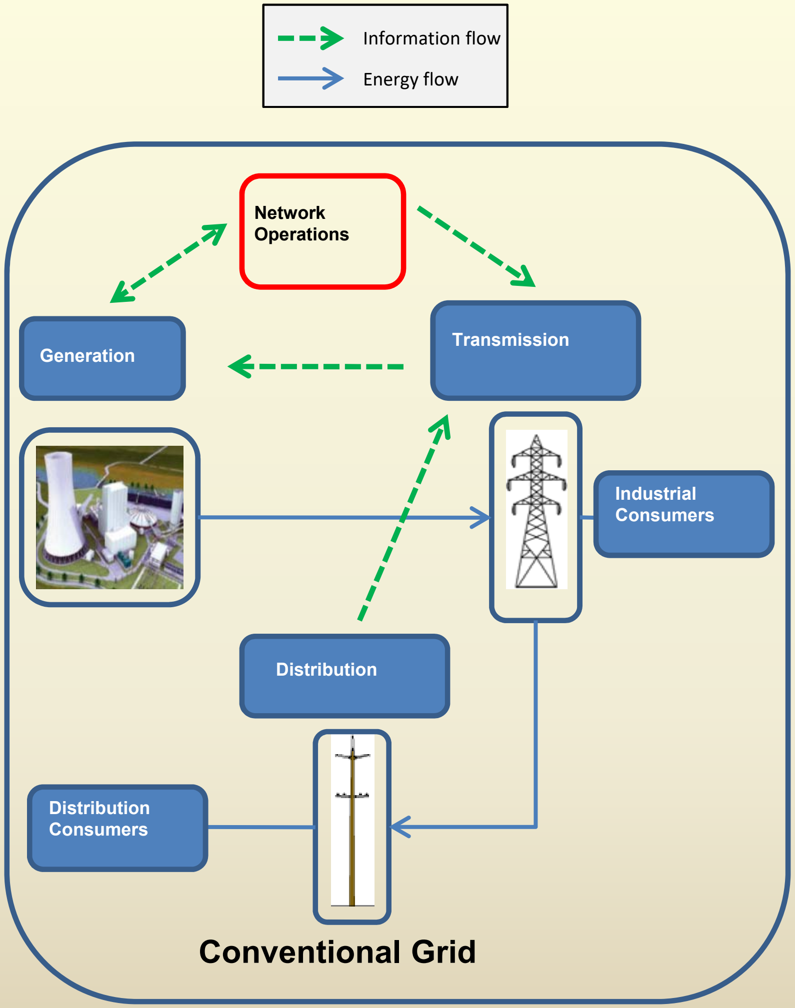
Current Power Grids and Control

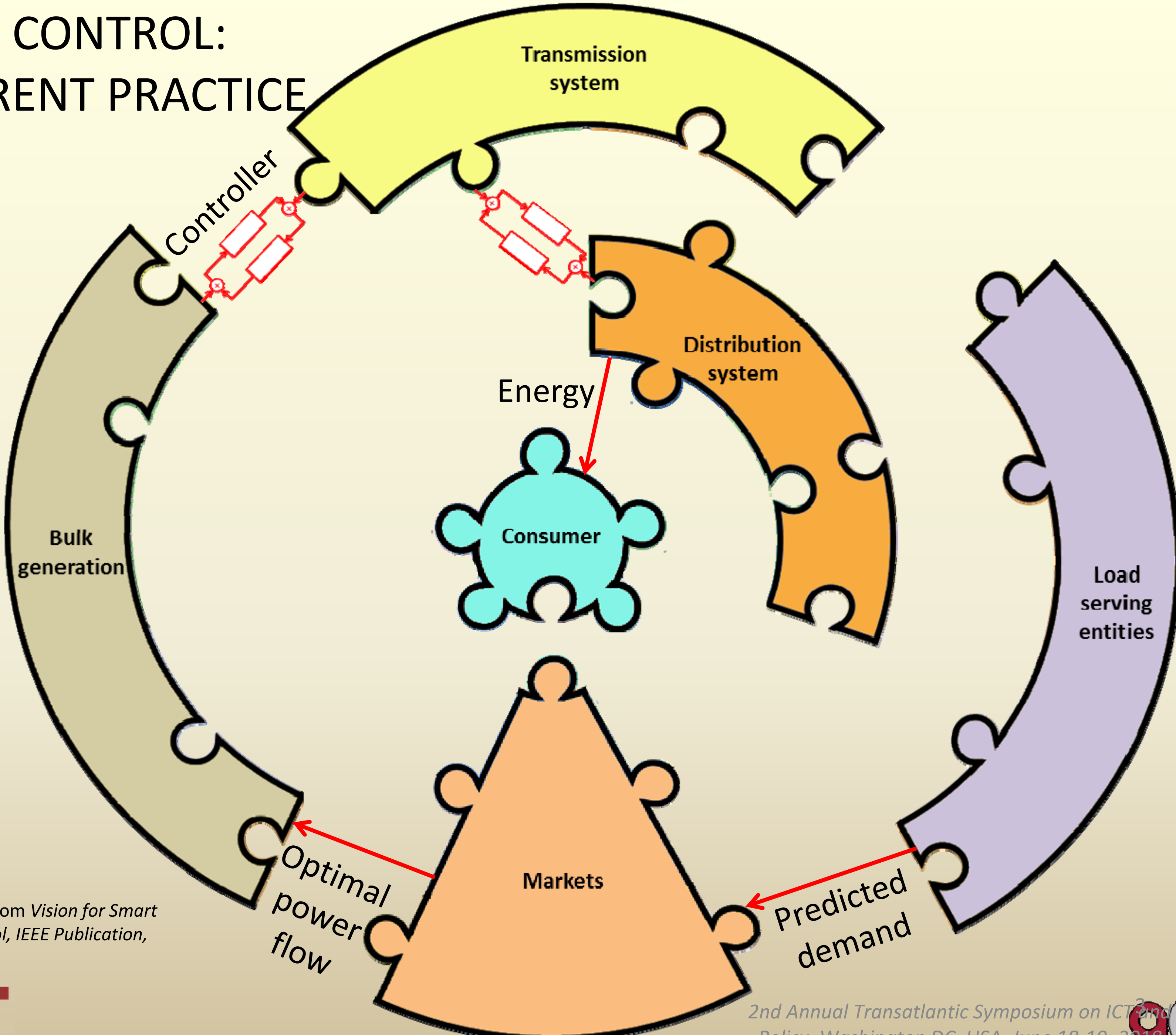


Control goals: Ensure

- Power balance
- Operating limits are maintained
  - Generators limit
  - Tie-lines limit
- Regulation of frequency (around 50 Hz or 60Hz).
- Regulation of voltage (around 110V or 220V)
- Maintain Transient Stability

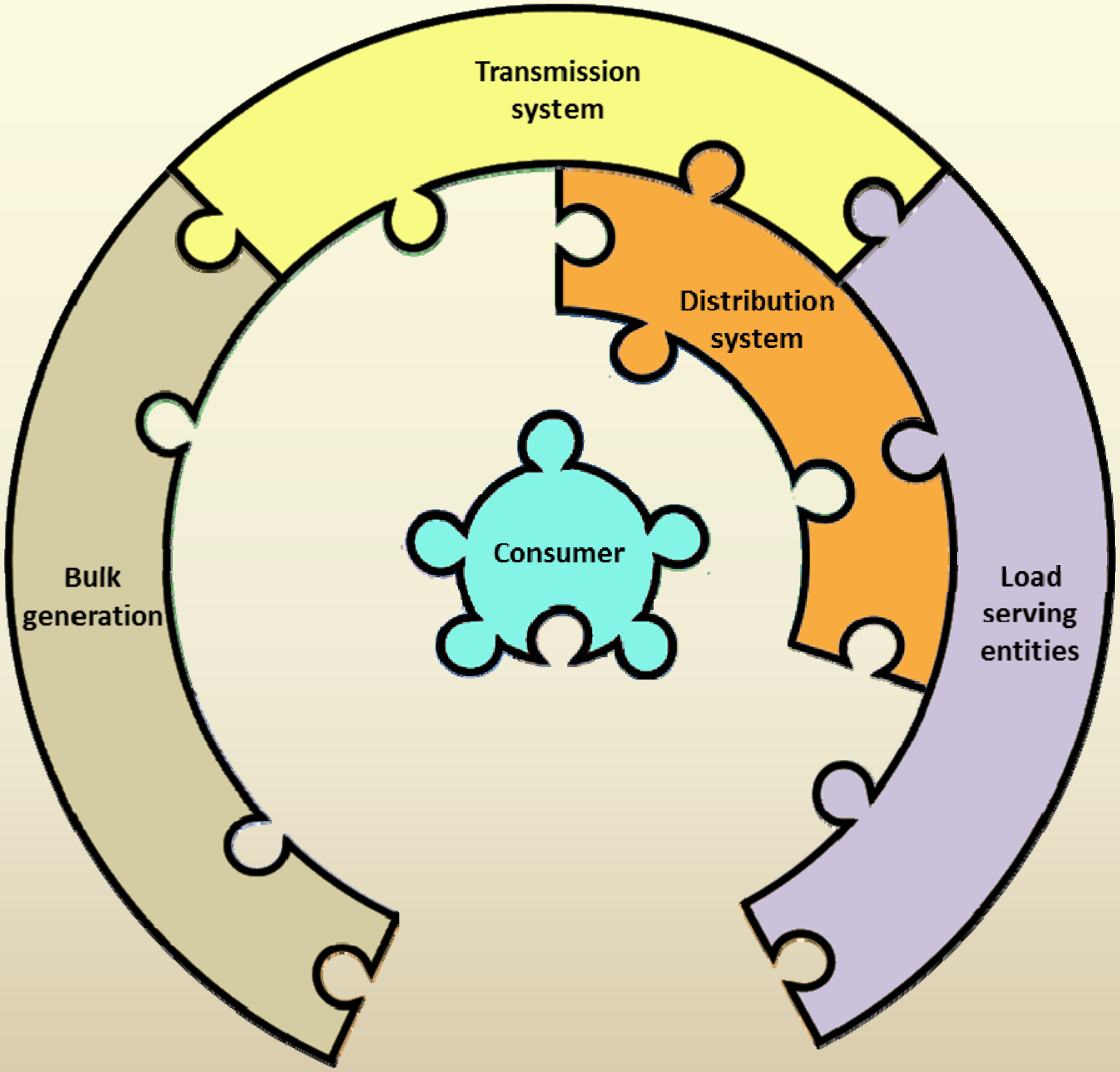
Significant drivers are causing drastic changes in the Power Grid landscape

GRID CONTROL: CURRENT PRACTICE

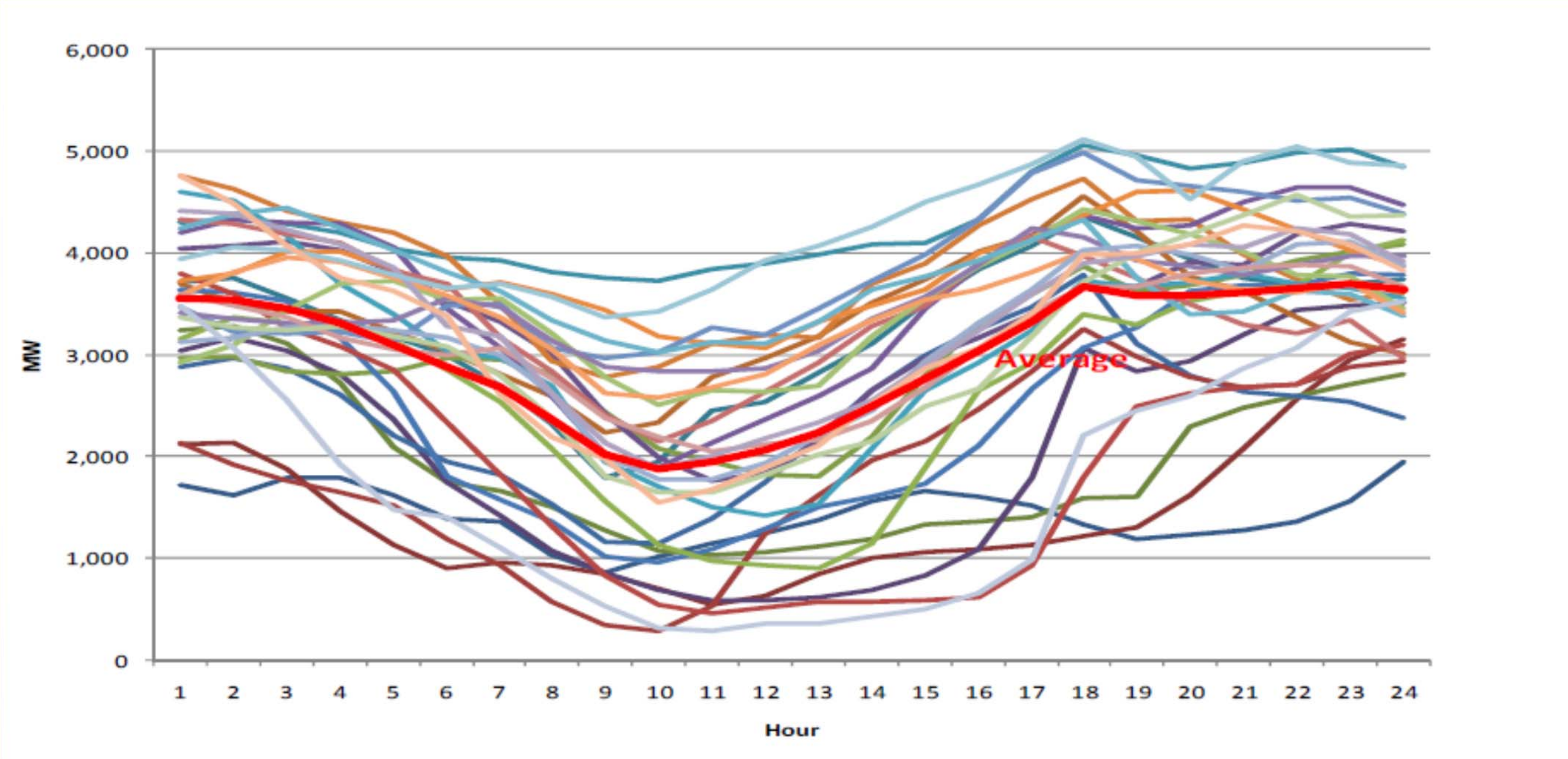


(adapted from *Vision for Smart Grid Control, IEEE Publication, 2013.*

GRID CONTROL: CURRENT PRACTICE

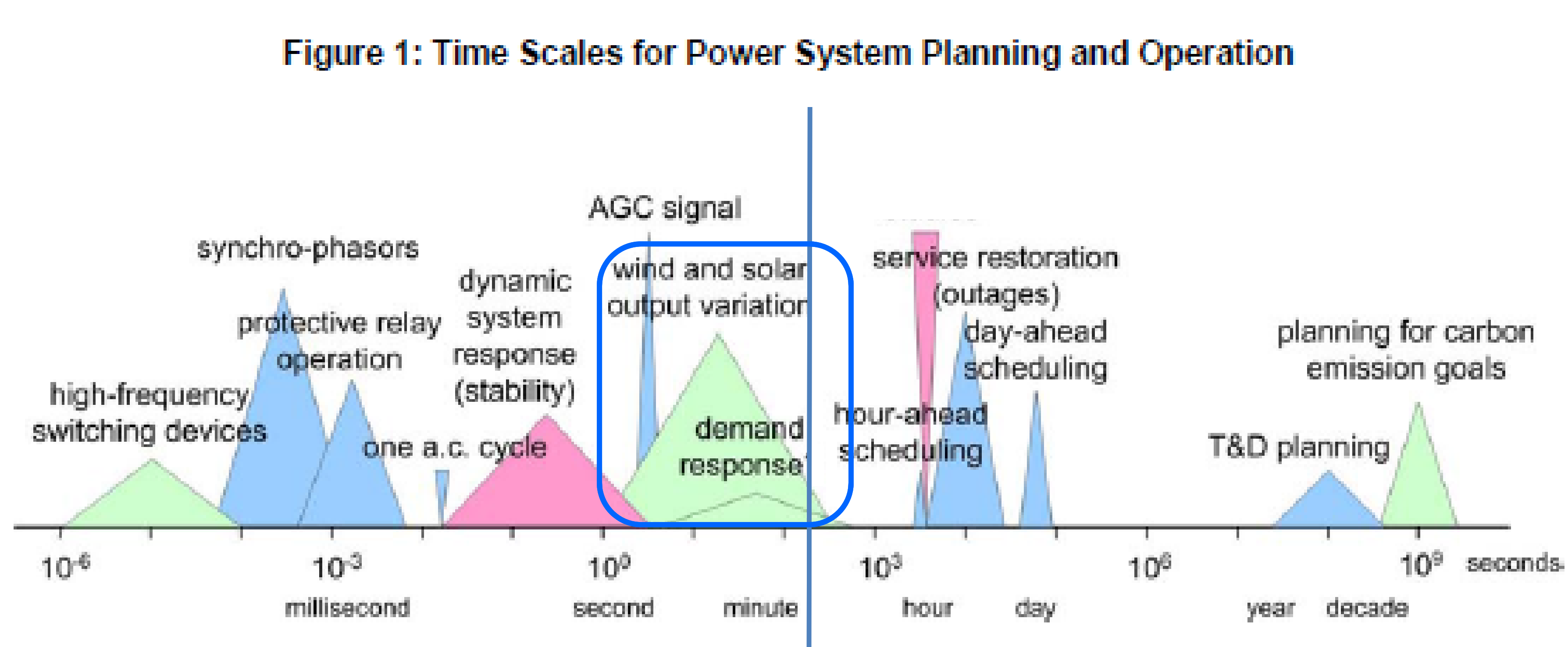


Intermittency: Wind Energy



From Integration of renewable resources, CA ISO Report, Aug. 2010.

"In almost every operating hour, wind could be producing across the full range of its potential production, from close to zero to almost maximum output."



(Source: California Energy Commission California Institute for Energy and Environment MAY 2014)

Operation

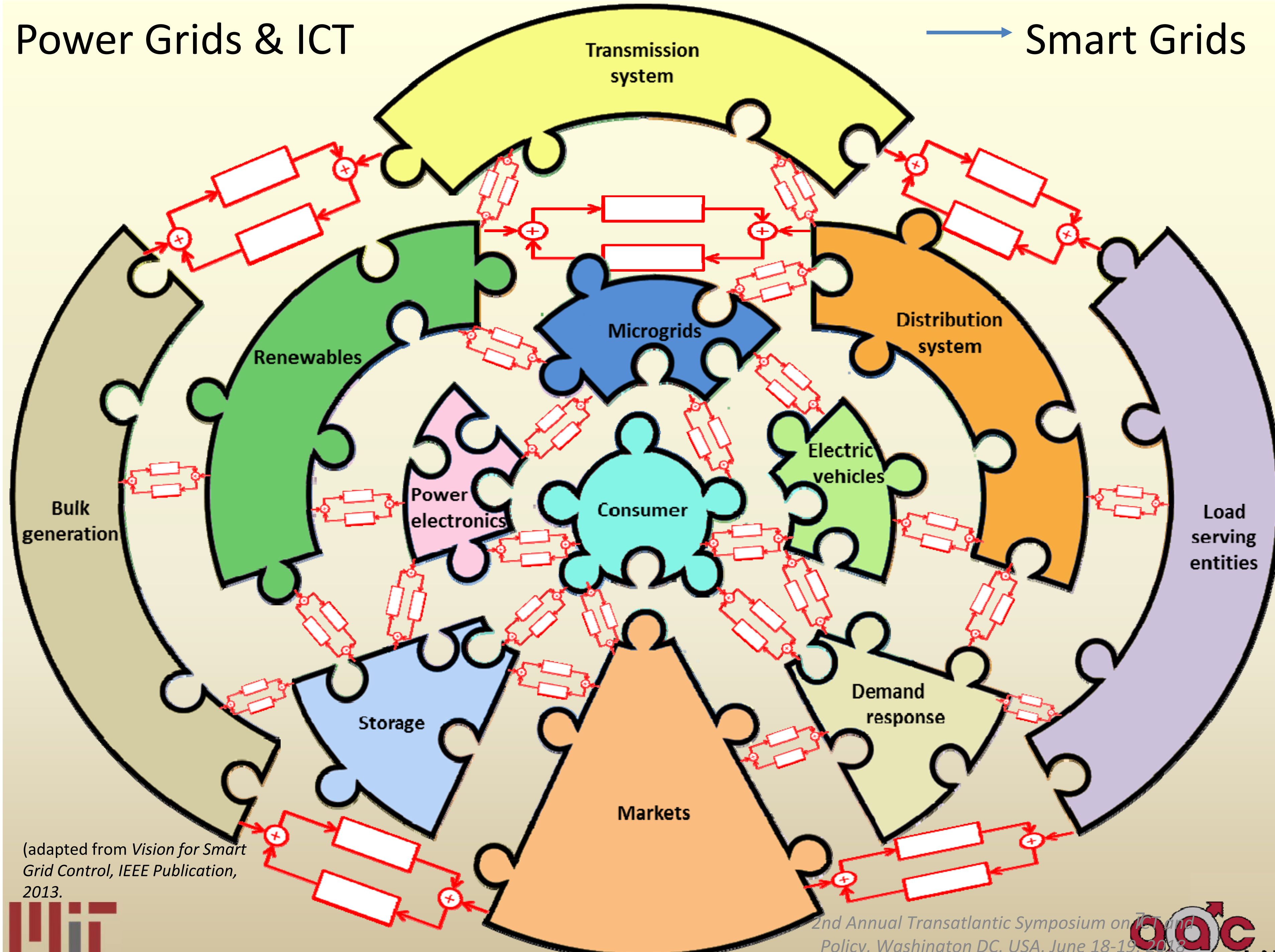
- Control for stability
  - Rotor angle
  - Frequency
  - Voltage
- Optimization
  - Power losses
  - Reactive power

Planning

- Markets – SCUC, DAM,RTM
- Regulatory concerns
- Policies

Reorganization of time-scales in markets and control is needed

Power Grids & ICT → Smart Grids



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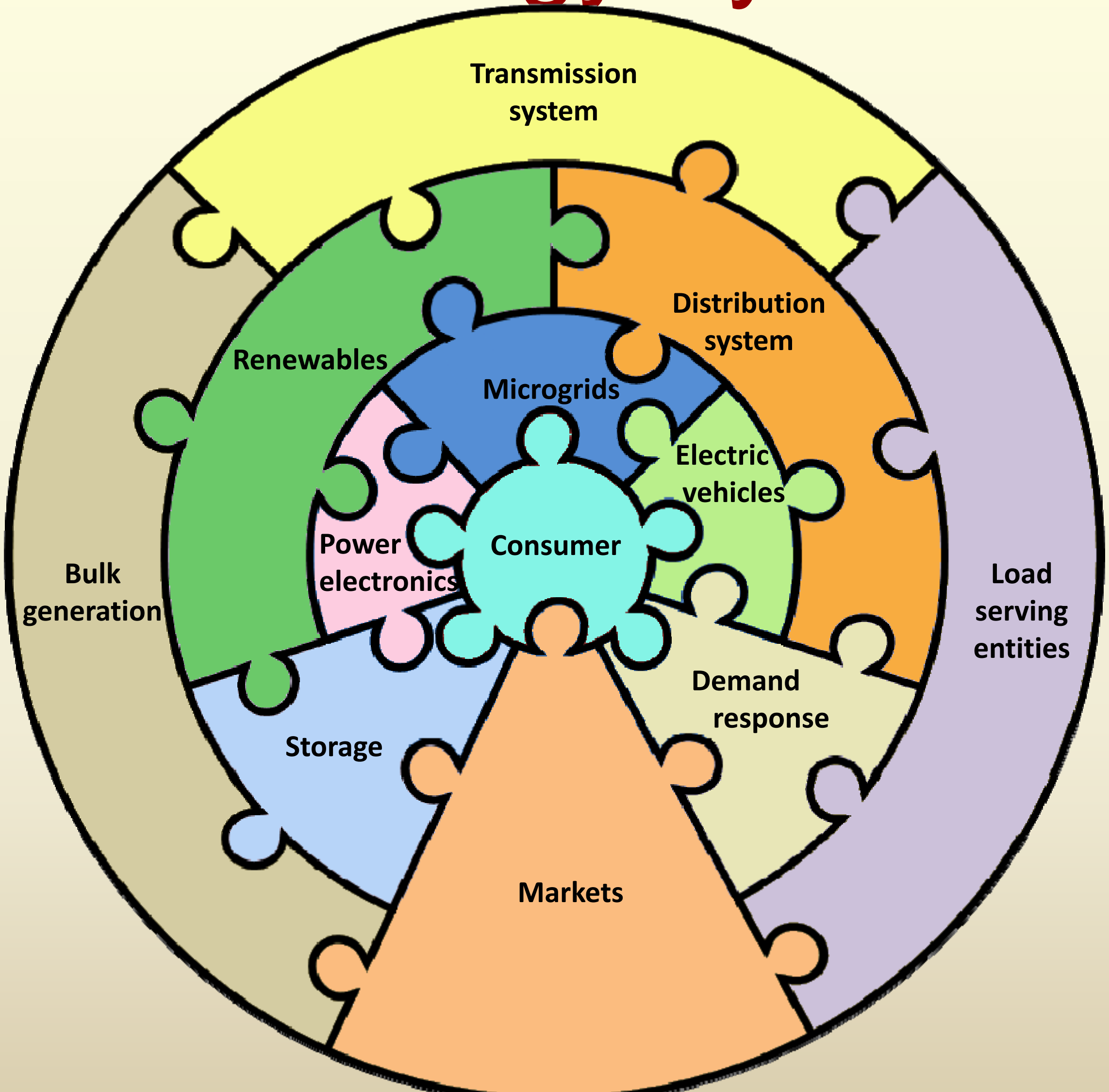
Smart Energy Systems



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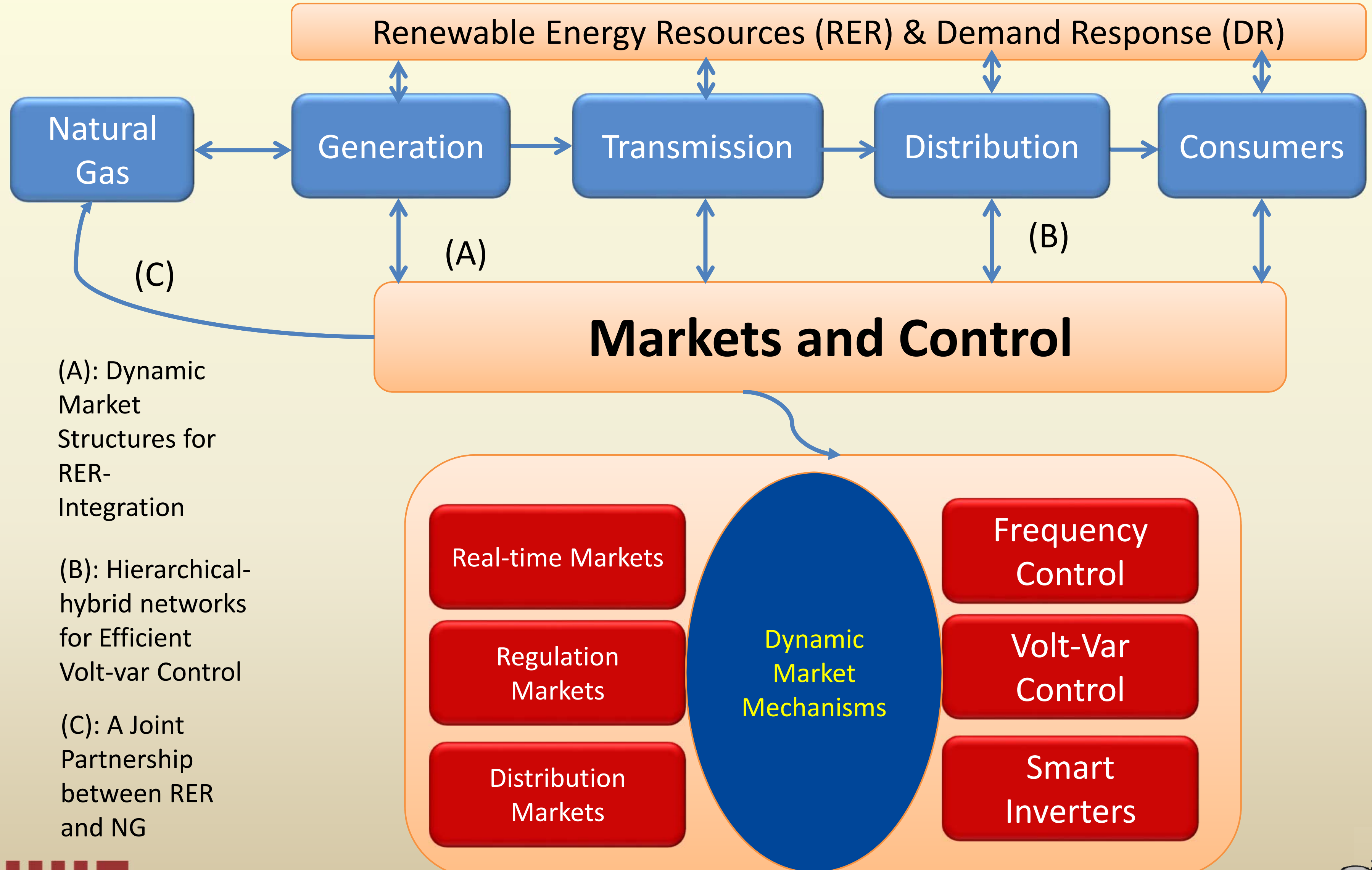
Role of ICT and real-time decision-making between disparate agents is central!

Opportunities for Smart Energy Systems



(A): Dynamic Market Structures for RER-Integration

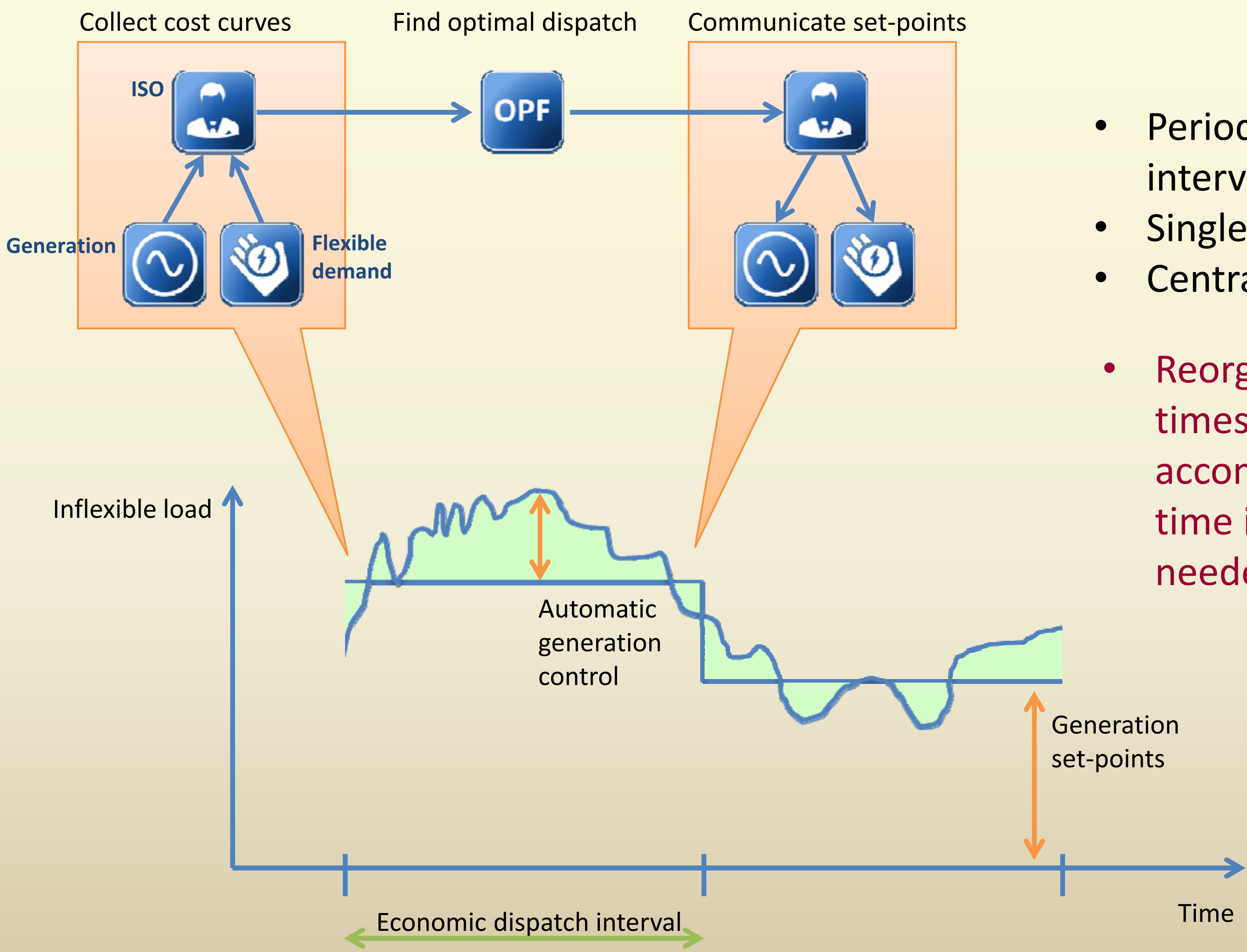
(B): Hierarchical-hybrid networks for Efficient Volt-var Control

(C): A Joint Partnership between RER and NG

BULK ENERGY AND TRANSMISSION:

(A) DMM FOR REAL-TIME MARKETS

Economic dispatch today

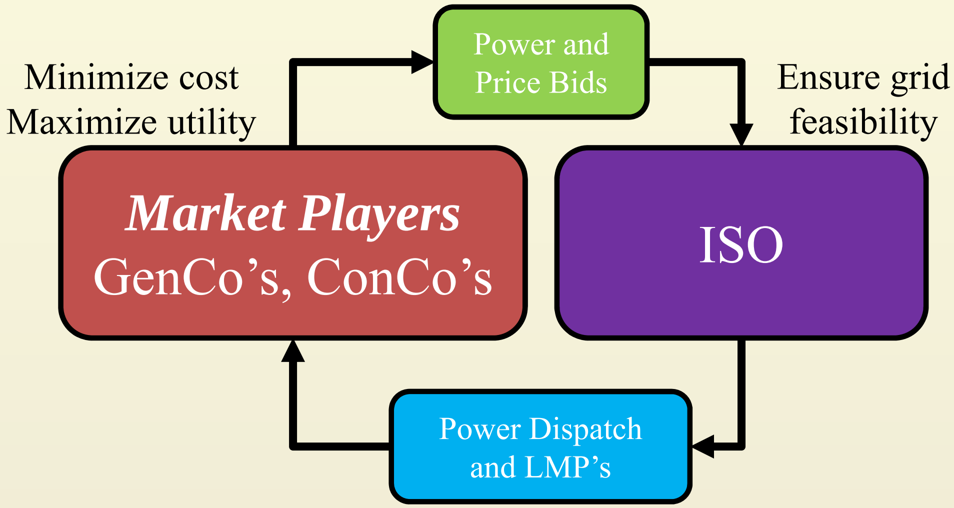


- Periodic with a regular interval.
- Single iteration process.
- Centralized computation.

- Reorganization of timescales to accommodate real-time information is needed.

DMM: A fast market solution that incorporates real-time data

- Approach: ***Iterative negotiations*** over a wide area network*



$$x^{k+1} = x^k + \Delta x^k$$

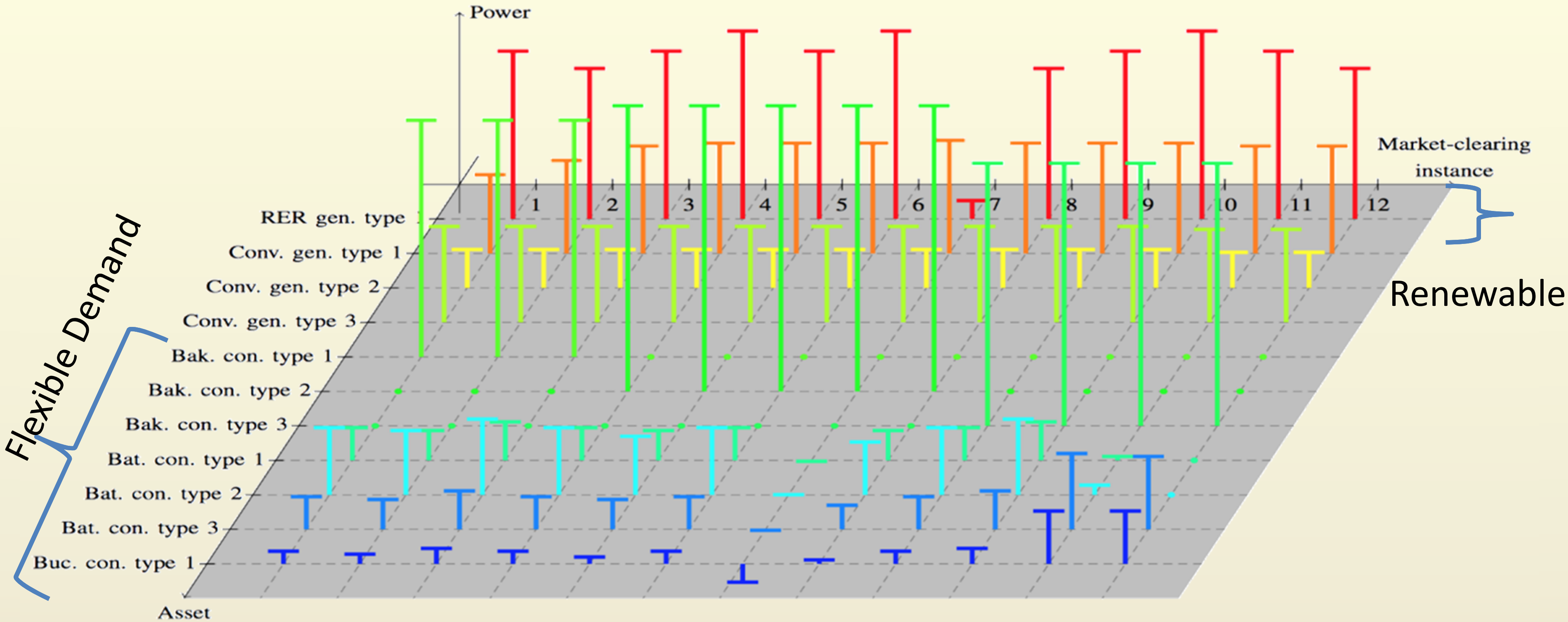
$$\lambda^{k+1} = \lambda^k + \Delta \lambda^k$$

x: states of players and ISO
λ: Lagrange multiplier (LMP)

- Challenges addressed:
  - Computation time
  - Most information must be kept private
  - Stability

$$x^k = \begin{bmatrix} P_{Gc}^k \\ P_{Gr}^k \\ P_{Dr}^k \\ \delta^k \end{bmatrix} \begin{matrix} \text{Conventional generation} \\ \text{Renewable generation} \\ \text{Demand response} \\ \text{Voltage angles} \end{matrix}$$

Possible Gains*: Ex. IEEE-118 bus



* J. Hansen, J. Knudsen, A. M. Annaswamy. "**A Dynamic Market Mechanism for Integration of Renewables and Demand Response,**" *IEEE Transactions on Control Systems Technology*, vol. 24, No. 3, 2016.

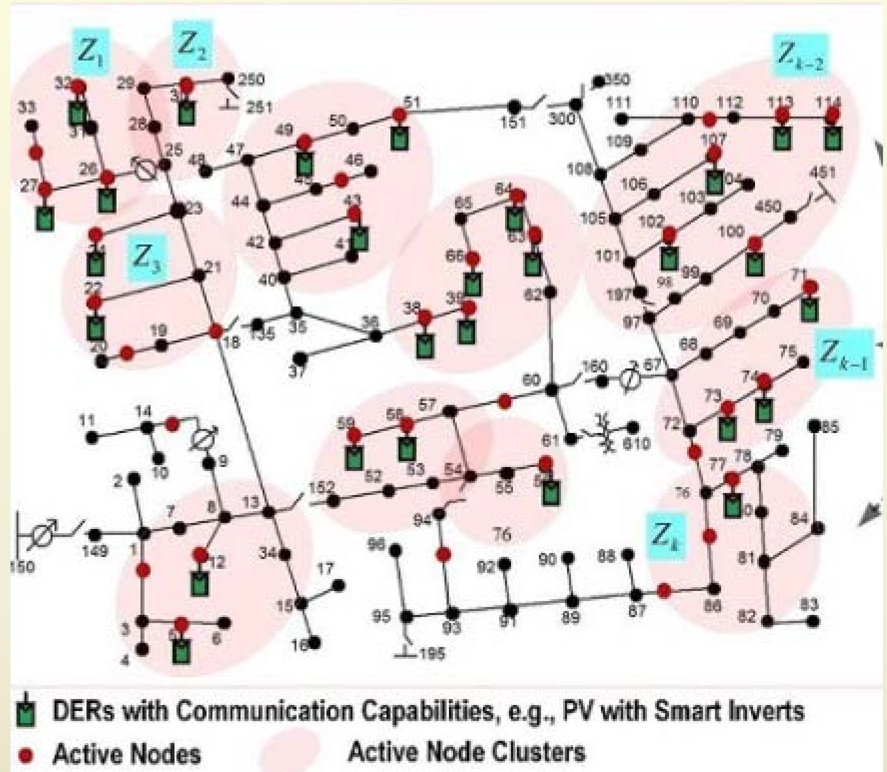
Challenges: Incorporation of multiple, strategic end-users
Multiple time-scales from Day-Ahead to Regulation Markets

DISTRIBUTION GRIDS:

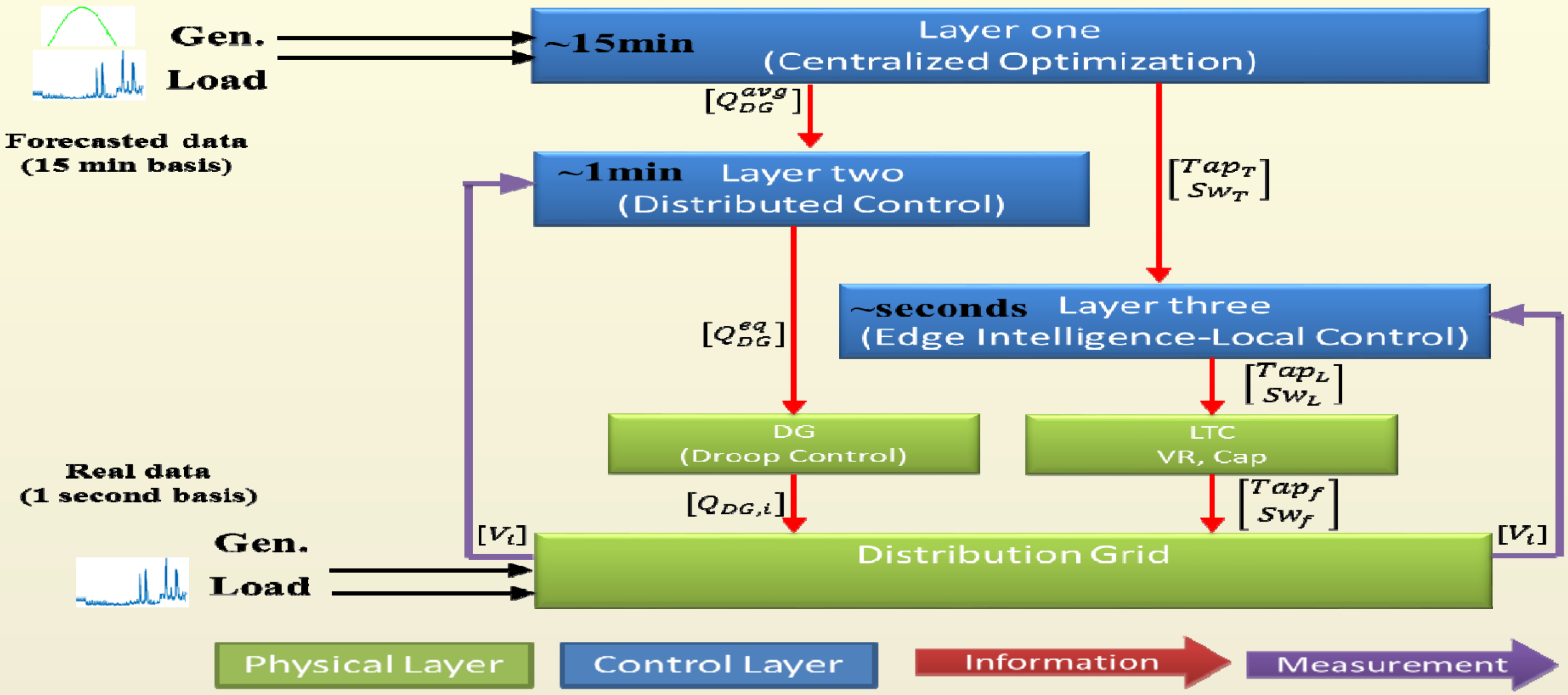
(B): HIERARCHICAL-HYBRID NETWORKS FOR EFFICIENT VOLT-VAR CONTROL

FEATURES OF DISTRIBUTED GRIDS

- Large number of nodes
- Increasing intelligence
  - ✓ Large Distributed Generation
  - ✓ Flexible Consumption
  - ✓ Storage can be integrated into the design
- Distributed paradigms are needed



A Possible Solution: Hierarchical-Hybrid Architecture*



- 3 to 10% reduction in active-power losses
- Within [0.93, 1.04]p.u.
- Minimal switches in tap settings

80% of the DGs were assumed to be renewables

Challenges:

- Distributed optimization with a large number of agents
- Need for a Retail Market

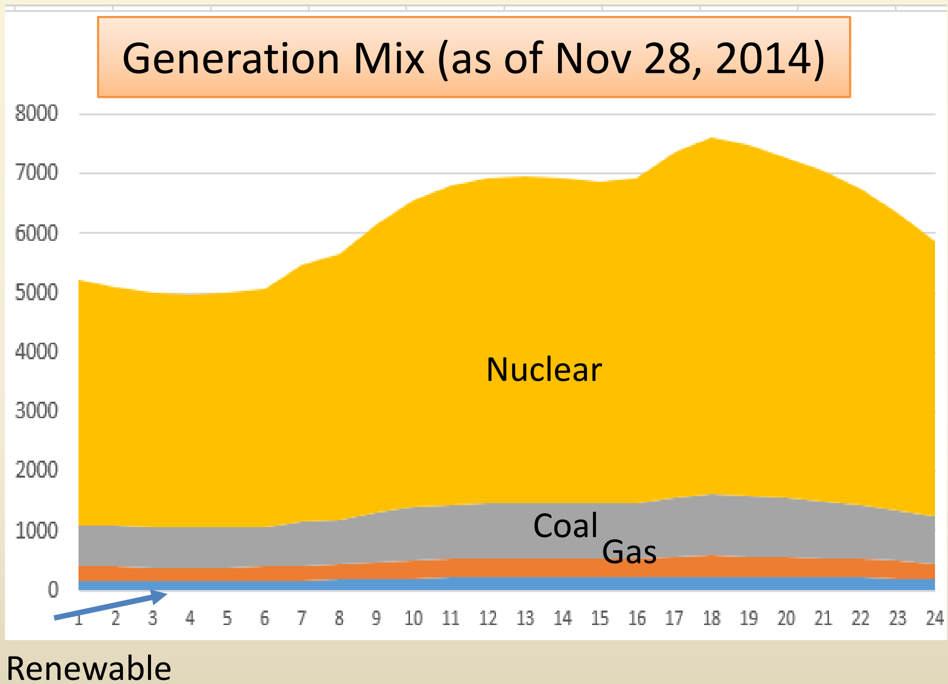
* A.R. Malekpour, A.M. Annaswamy, J. Shah, "**Resilient control designs for smart distribution grids, Resiliency of Power Distribution Systems**" (eds. Srivastava, Liu, and Chanda) Springer, 2018.

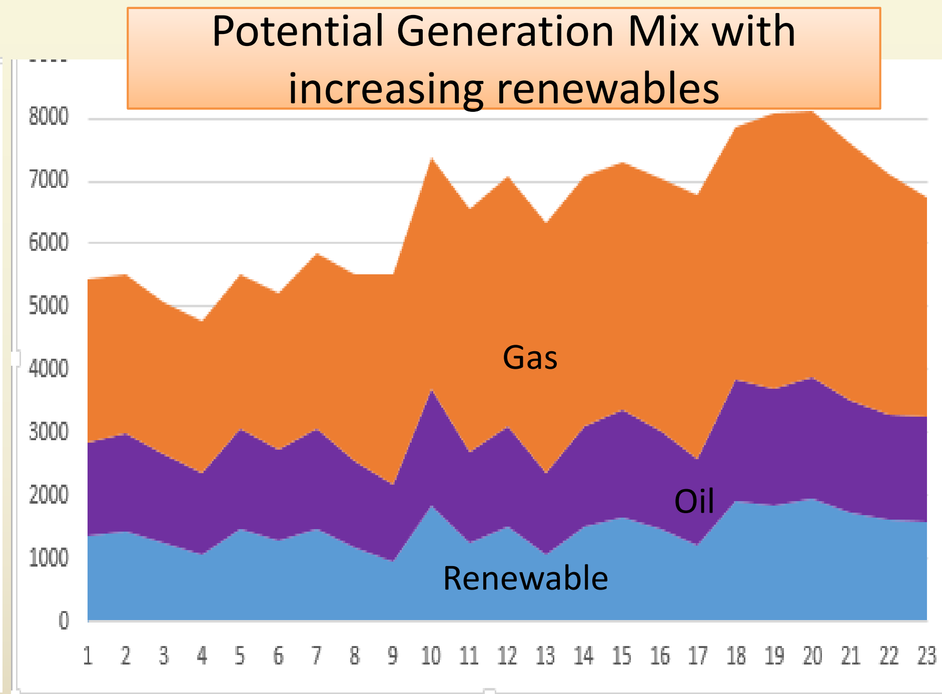
NATURAL GAS AND ELECTRICITY INFRASTRUCTURES

(C): MODELS FOR ESTIMATION OF GAS PRICES AND GAS BID-VOLATILITY

Implications of Renewable Generation

$$demand\ G_d = \cancel{G_{coal}} + \cancel{G_{nuclear}} + G_{oil} + \boxed{G_{gas}} + G_{hydro} + \boxed{G_{solar} + G_{wind}}$$





Challenges:

- Misalignment in Gas and Electricity Markets; Unequal access to G_{gas}

Implications of Renewable Generation

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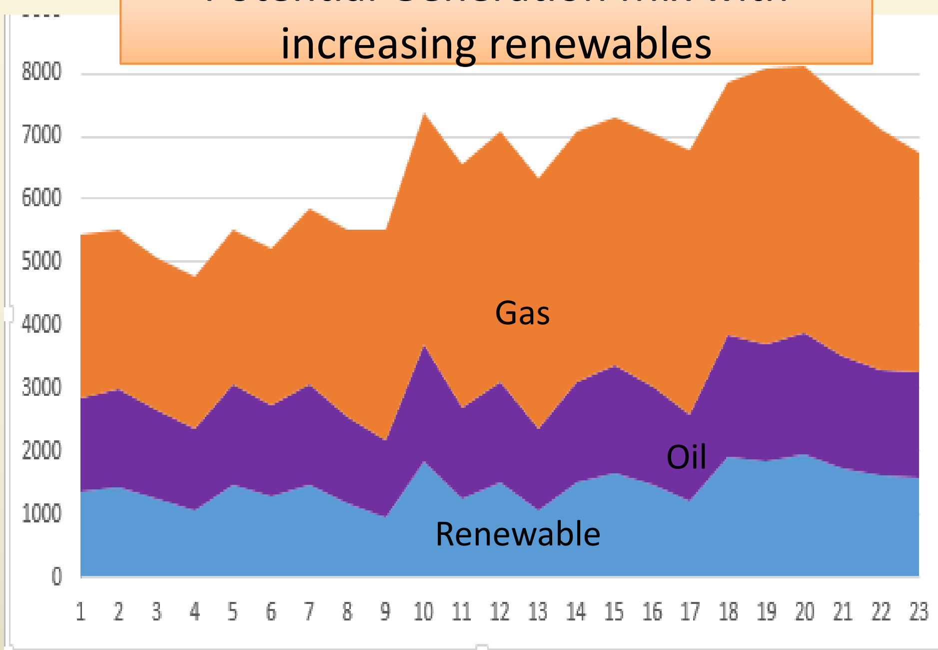
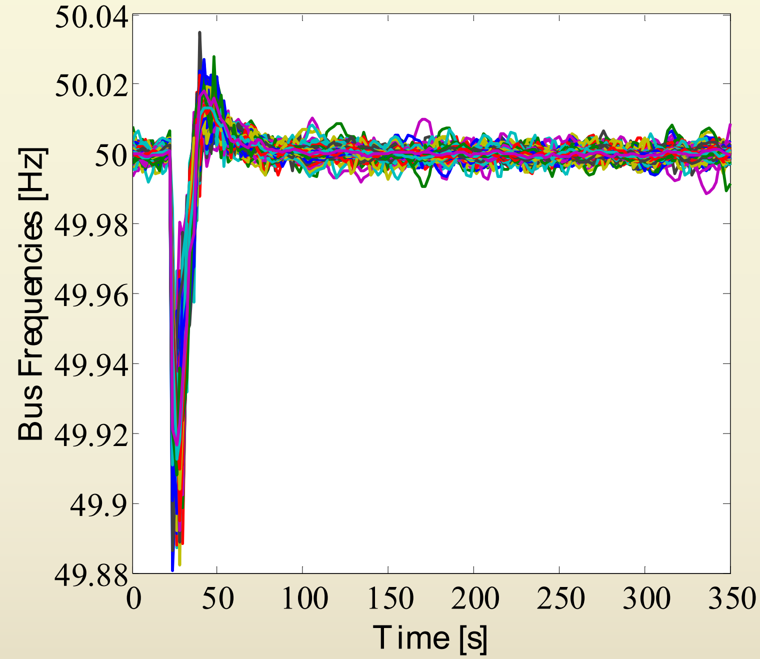
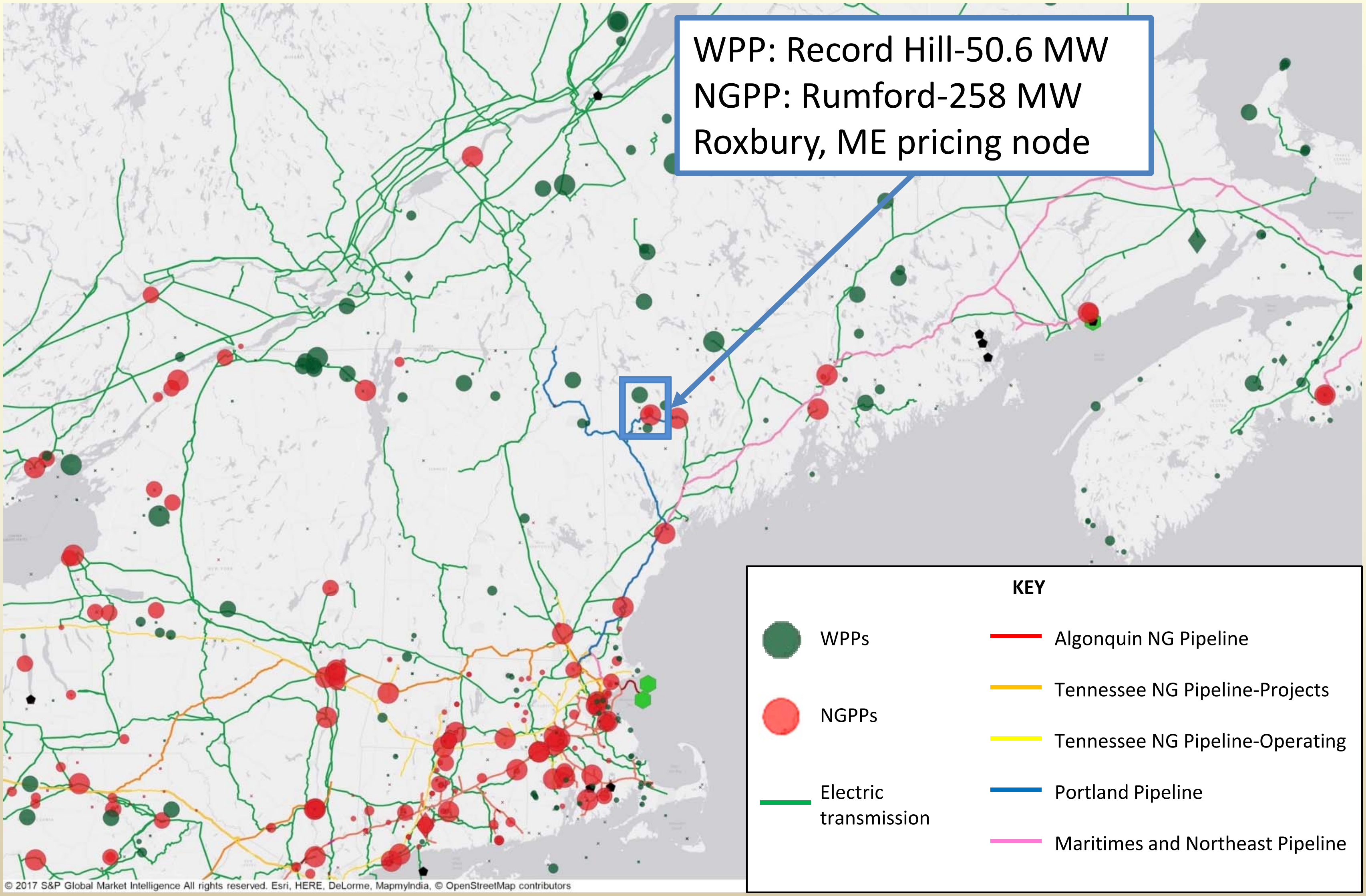
Potential Generation Mix with increasing renewables





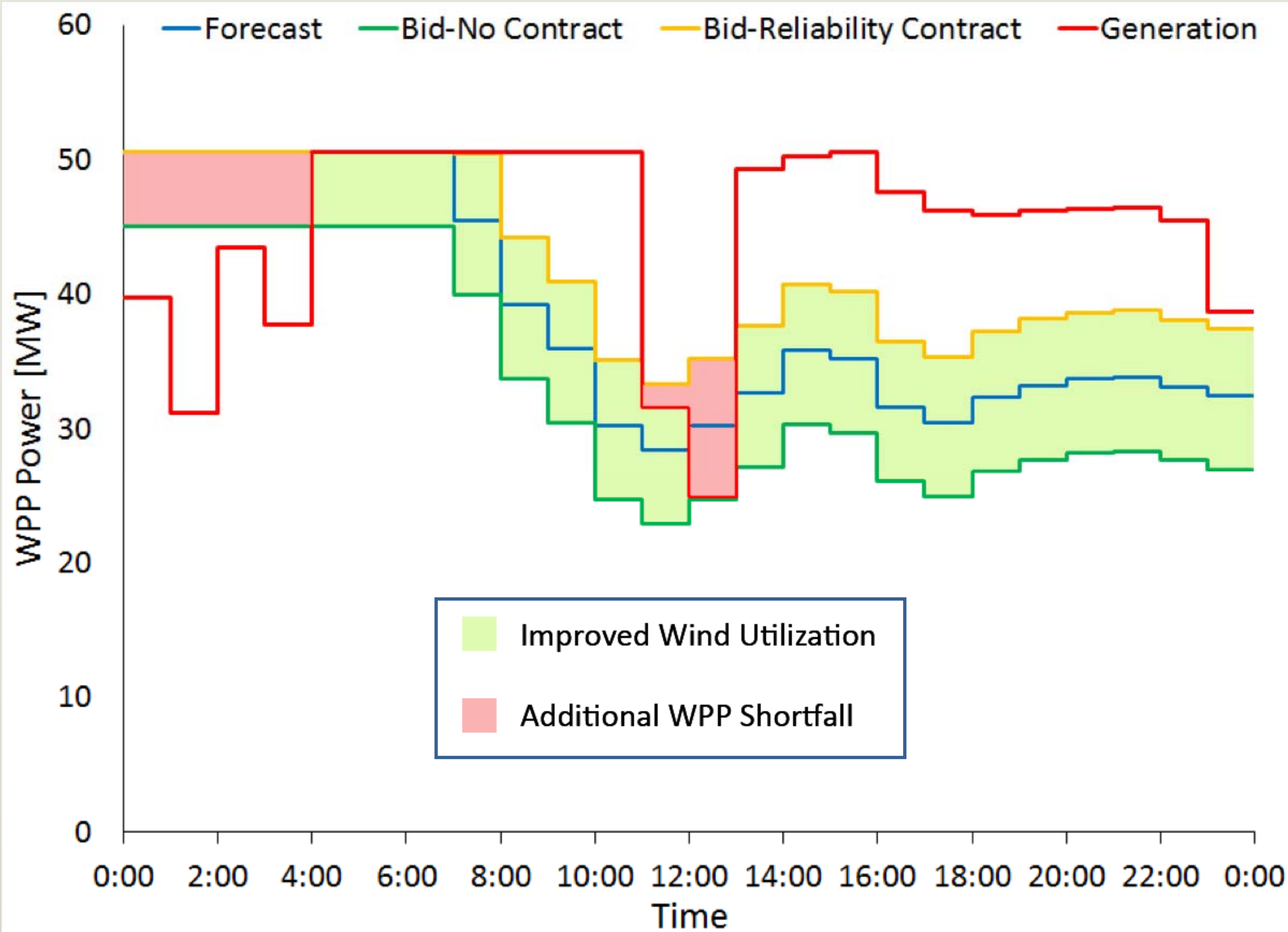
- If gas plants cannot meet their dispatch needs hourly and make up for renewable generation fluctuations, there can be a power imbalance, leading to frequency errors

Reliability Contracts between WPP and NGPP?



Map developed in SNL Energy-S&P Global Market Intelligence

Simulation – Improved Renewable Utilization



WPP generation developed with NREL-System Advisory Model

Simulation – Reliability Contract Yearly Cash Flows*

Contract Between WPP and NGPP	NO		YES	
Power Plant	WPP	NGPP	WPP	NGPP
Day-Ahead Energy Market Income	$ 2,223,008	$ 19,699,267	$ 4,253,378	$ 19,699,267
Contract Payment	$ -	$ -	-$ *2,484,849*	$ 2,484,849
Day-Ahead Penalties	-$ 1,520,554	$ -	$ -	-$ 238,007
Fuel Cost	$ -	-$ 7,690,365	$ -	-$ 8,671,295
Variable O&M Cost	$ -	-$ 1,446,424	$ -	-$ 1,646,660
Fixed O&M Cost	-$ 534,633	-$ 9,368,111	-$ 534,633	-$ 9,368,111
Profit	$ 167,820	$ 1,194,367	$ 1,233,895	$ 2,260,042

α set to 3
β calculated as 1.538

Renewable utilization increase from 66% to 78%

Yearly profits increase by $1.07 million for each party

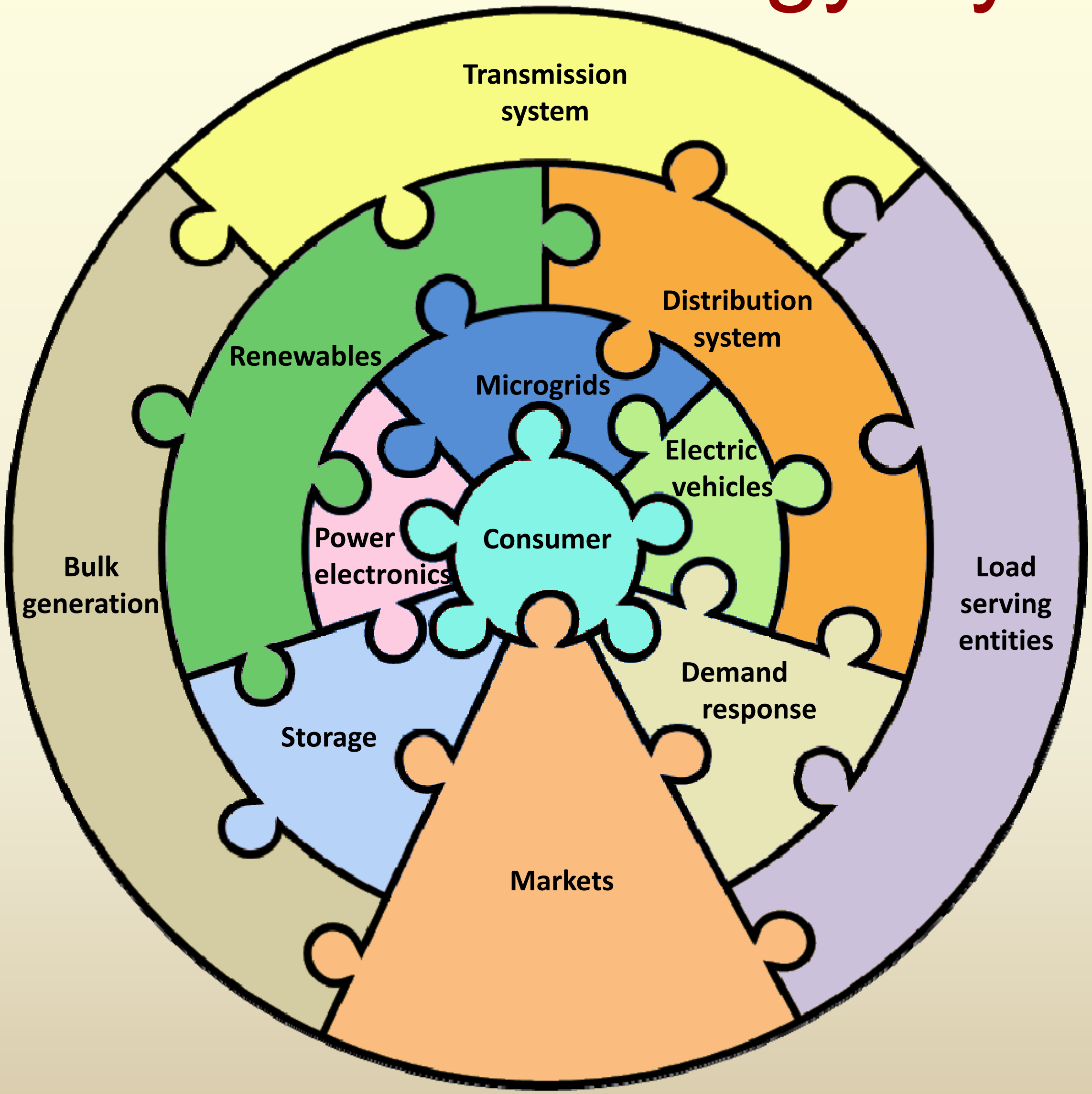
* D. D'Achiardi, N. Aguiar, S. Baros, V. Gupta, and A.M. Annaswamy, "Reliability Contracts between Renewable and Natural Gas Power Producers," IEEE TCNS (submitted), 2018.

Challenges & Opportunities

- Large and varied uncertainties and intermittencies
- Significant conflicts between local objectives and global outcomes
- Disparate network and regulation structures in the gas and electricity infrastructures.
- 100% renewable penetration
- Resilient and reliable power delivery

[1] Brown, P. *How does wind generation impact competitive power markets?*. Congressional Research Service, 2012.
[2] Bitar, E., et al. "Selling random wind." *2012 45th Hawaii International Conference on*. IEEE, 2012

Vision for Smart Energy Systems



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