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Inventing an Energy Internet

The Role of Anticipation in Human-Centered Energy Distribution and Utilization

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Introduction

- Secure and reliable energy delivery becomes a pressing challenge
  - Increasing demands with higher quality of service
  - Declining resources
- The North American electric power grid is operating under narrower safety margins
  - More potential for blackouts/brownouts
  - Efficient and effective management strategy needed
- Current energy delivery infrastructure is a super complex system (more *evolved* than *designed*)
  - Lack of accurate and manageable models
  - Unpredictable and unstable dynamics
- Can we build an inherently stable energy network for future generations?

Anticipation and Orthogenesis

- *Anticipation* governs system performance over the short term (tactical) [Rosen, 1985]

- *Orthogenesis* governs system development over the life span (strategic) [Crain, 2000]. Orthogenesis controls development towards
  - Increasing differentiation of systems that initially fused in a global system
  - Systems that are more differentiated emerge over time which become more distinct yet develop to be more integrated
  - The more advanced systems (more differentiated, specified and internally integrated) hierarchically regulate the less developed systems

- Through anticipation and orthogenesis we can build in "intentionality" [Freeman, 2000]
  - *intentionality = unity + wholeness + purpose*

Crain, W, *Theories of Development: Concepts and Applications*, 4th Edition, Prentice Hall, 2000
Rosen, R., *Anticipatory Systems*, Prentice Hall, 1985
Freeman, W.J., *How Brains Make Up Their Minds*, Columbia University Press, New York, 2000

Smart Grids

- Smart grids is an advanced concept
  - Detect and correct incipient problems at their very early stage
  - Receive and respond broader range of information
  - Possess rapid recovery capability
  - Adapt to changes and reconfiguring accordingly
  - Build in reliability and security from design
  - Provide operators advanced visualization aids
- Most of these features can be found in the information Internet
  - The Internet is also a super complex system
  - It is remarkably stable
- Can we find an Internet type of network for energy systems?

An Energy Internet

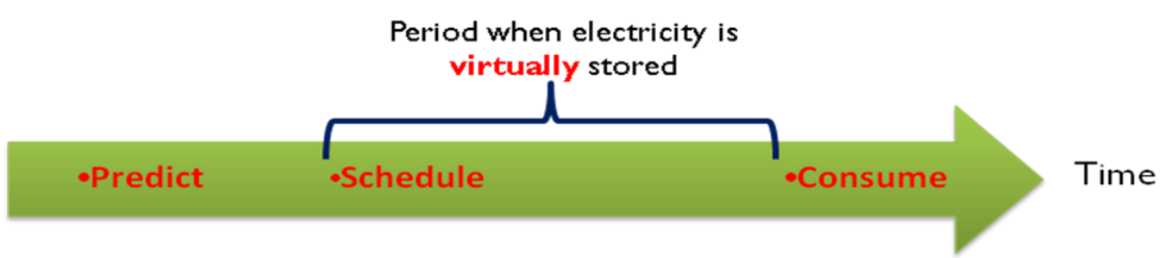
- Benefits of an energy internet
  - Reliability
    - Self configuration and self healing
  - Flexibility and efficiency
    - Customers can choose the service package that fits their budget and preferences
    - Service providers can create more profits through real-time interactions with customers
    - Marketers or brokers can collect more information to plan more user-oriented marketing strategies
    - The regulation agency can operate to its maximal capacity by focusing effectively on regulating issues

Challenges and Gaps

- Existing energy infrastructure is not ready for upgrading to an energy internet
- Differences between digital data and electricity
  - Electricity is mainly generated centrally and consumed locally
    - Long distance transmission and traffic control are critical.
  - Electricity cannot be stored at a large scale
    - Storage, served as buffers, is an important stabling factor in a complex system
  - The Internet uses a "Best-Effort" service model. The energy network, however, assumes the opposite
- The key is to achieve an effective storage for electricity, if not physically, then virtually

Virtual Storage of Electricity

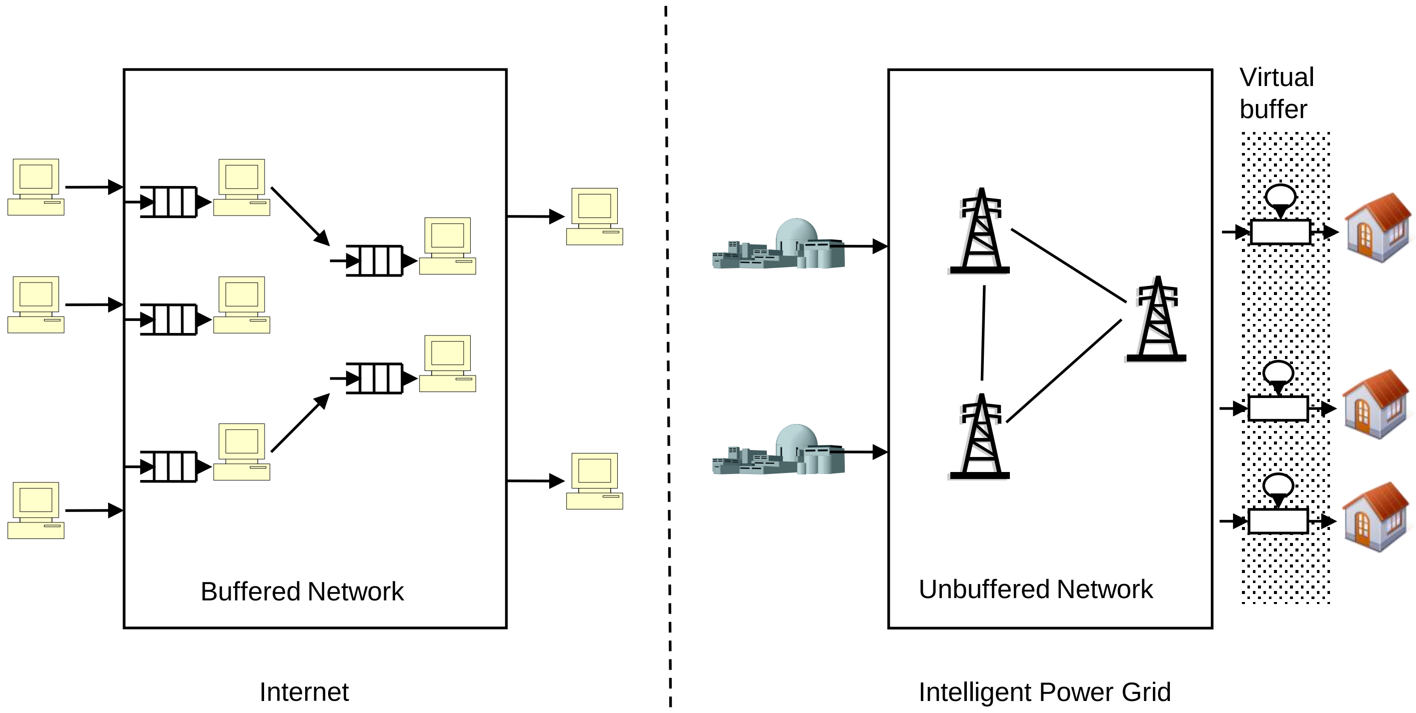
- **Assumption 1:** *Intelligent management and sharing of information achieve virtual energy storage*
  - Intelligent meters make it possible to dynamically schedule the use of electricity of every customer
  - Dynamic scheduling creates a sheet of virtual buffer between generation and consumption



Price Elasticity

- Assumption 2: *Price elasticity can effectively manage uncertainty*
- Price elasticity: $E_d = \frac{dQ}{dP}\frac{P}{Q}$
  - where *P* and *Q* are price and demand respectively
- Price elasticity is used to characterize the sensitivity of customers to the change in price
- With short term price elasticity, a delicate balance between generation and consumption can be achieved through dynamical negotiations
  - Forecasting uncertainty can be tolerated

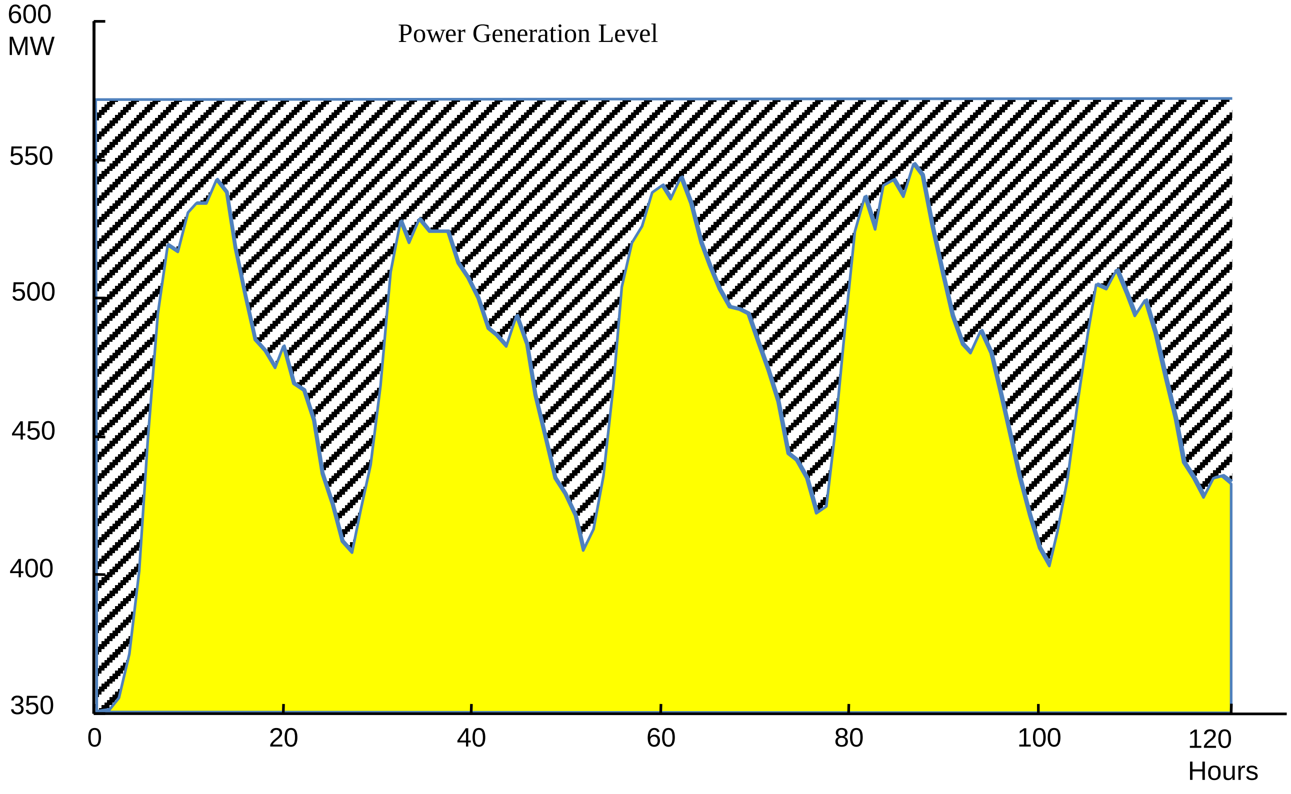
Comparison



Buffered Network
Internet
Virtual buffer
Unbuffered Network
Intelligent Power Grid

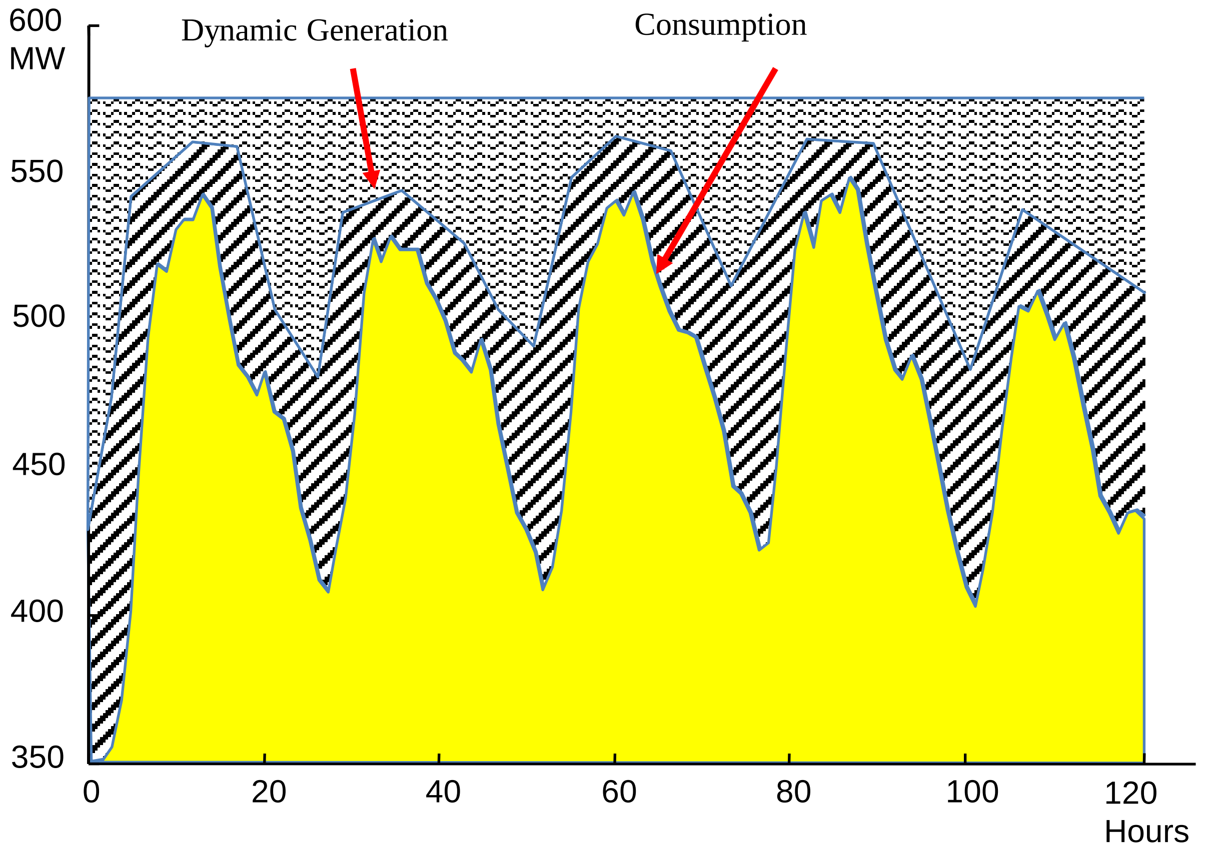
Saving is Conserving (I)

- Without anticipation, energy waste is enormous



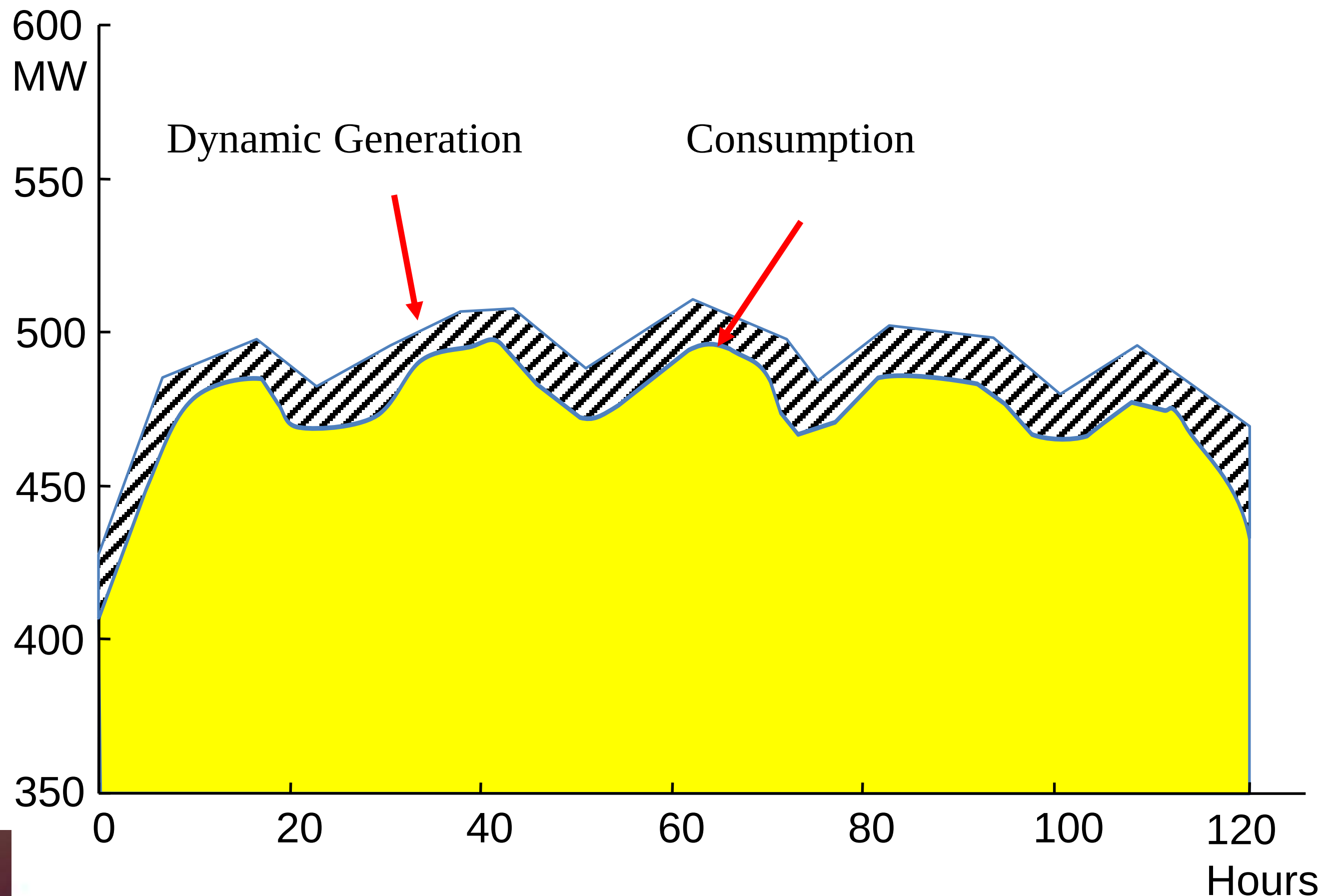
Saving is Conserving (II)

- With anticipation, energy waste can be dramatically reduced



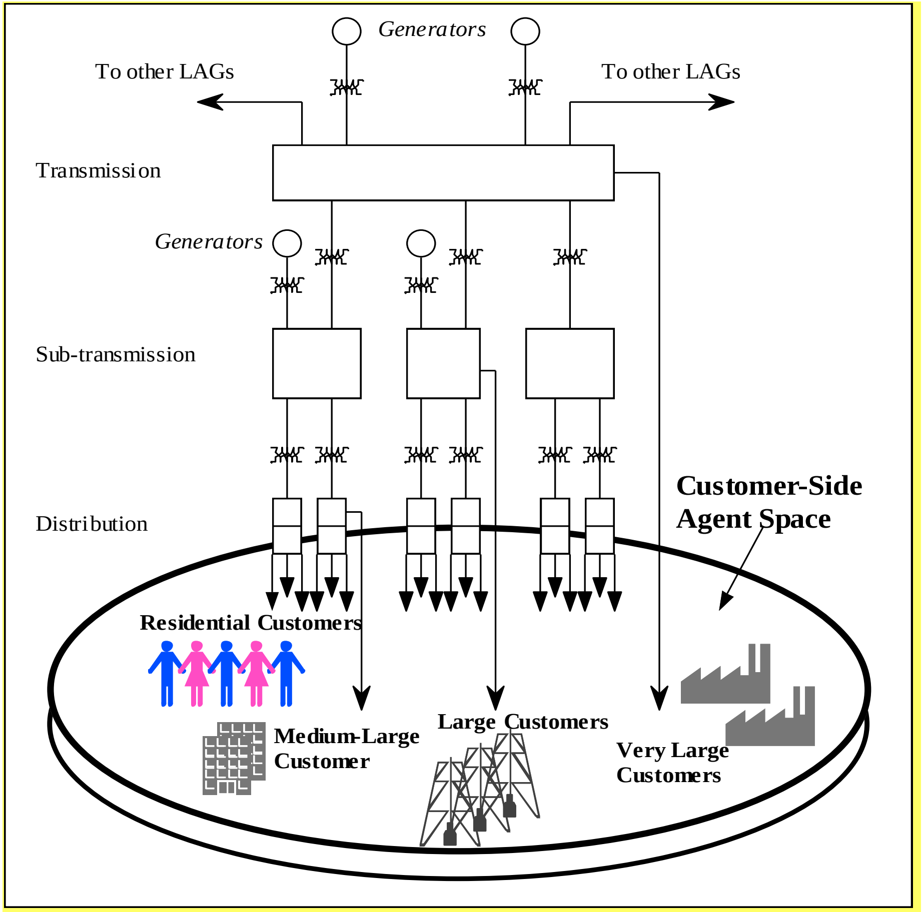
Saving is Conserving (III)

- Anticipation and price elasticities result in energy saving and elevated stability



Example Architecture: CIMEG

- The example was developed by the *Consortium for Intelligent Management of Electric-power Grid (CIMEG)*.
- CIMEG advanced an anticipatory control paradigm with which power systems can act proactively based on anticipation of power behavior and early perceptions of potential threats
- It uses a bottom-up approach to circumvent the technical difficulty of defining the global health of a power system at the top level



Smart Meter

- Requirement 1: *Smart meter with unique address and communication capability*
- The real-time interactions between suppliers and consumers need to be automated
- Everything starts from a smart meter installed on the customer side
- The smart meter is equipped with a unique and addressable identifier and two-way communication capability

Forecasting

- Requirement 2: *Forecasting capability*
- Prediction and anticipation are the essential stabilizing forces in a complex system
- For an energy internet, it is crucial that customers’ energy usage patterns can be predicted with a degree of certainty
- Many forecasting models are available
  - Parametric (statistical)
  - Non-parametric (neural networks)
  - Hybrid (fuzzy logic) methods

Multi-resolution agents

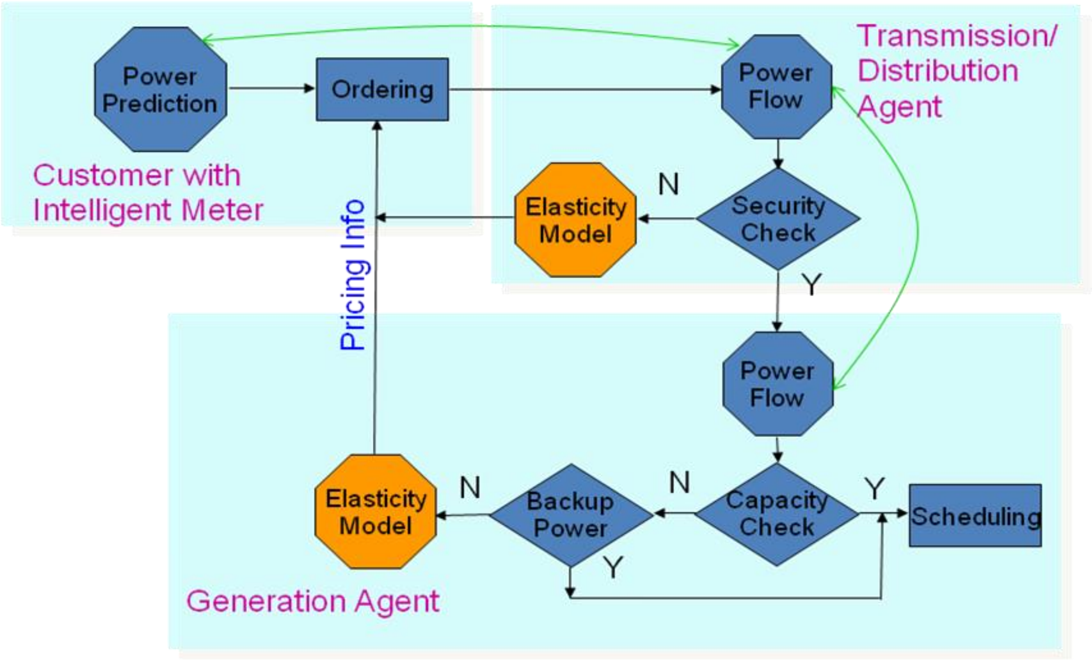
- Requirement 3: *Multi-resolution agents*
- Intelligent agents have to be implemented to act on behalf of entities such as customers and suppliers
- Conventional game theory is not effective to govern the action of an intelligent agent
  - Prisoner’s Dilemma
- A multi-resolution agent has different accuracy (resolution) regarding the immediate and remote futures
- Multi-resolution agents enable collaborations to achieve best payoffs for all

Short-term price elasticity model

- Requirement 4: *Short-term price elasticity model*
- Price elasticity measures how the price change impacts the customers' willingness to consume power
- A good short-term price elasticity model provides the basis for interactions between customers and suppliers

Protocol: Example

- An example protocol describing the interactions among agents



Conclusions

- An energy internet is a potential answer to some pressing world energy challenges
- Technological innovations in IT, instrumentation, communications and control have made it possible
- Investigations of system fundamentals, (e.g., development, semiosis, intentionality) are needed to steer network evolution
- There is a number of requirements that need to be met in order to build an energy internet
- The keywords are anticipation and control
  - Anticipation provides valuable information to achieve virtual storage of energy
  - Price elasticities can be used to achieve effective control