Implementing Virtual Buffer for Electric Power Grids

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Electric power grid as a complex system

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Complex Systems

- A complex system consists of a large number of interacting and interwoven parts
- The overall behavior of a complex system cannot be fully explained by an understanding of its component
  - The aggregation of a large number of simple components could exhibit very different complex property
- Usually, a complex system is non-deterministic
- A complex system could be sensitive to initial conditions
- Complex systems are difficult to model but possible to manage

Electric Power Grid

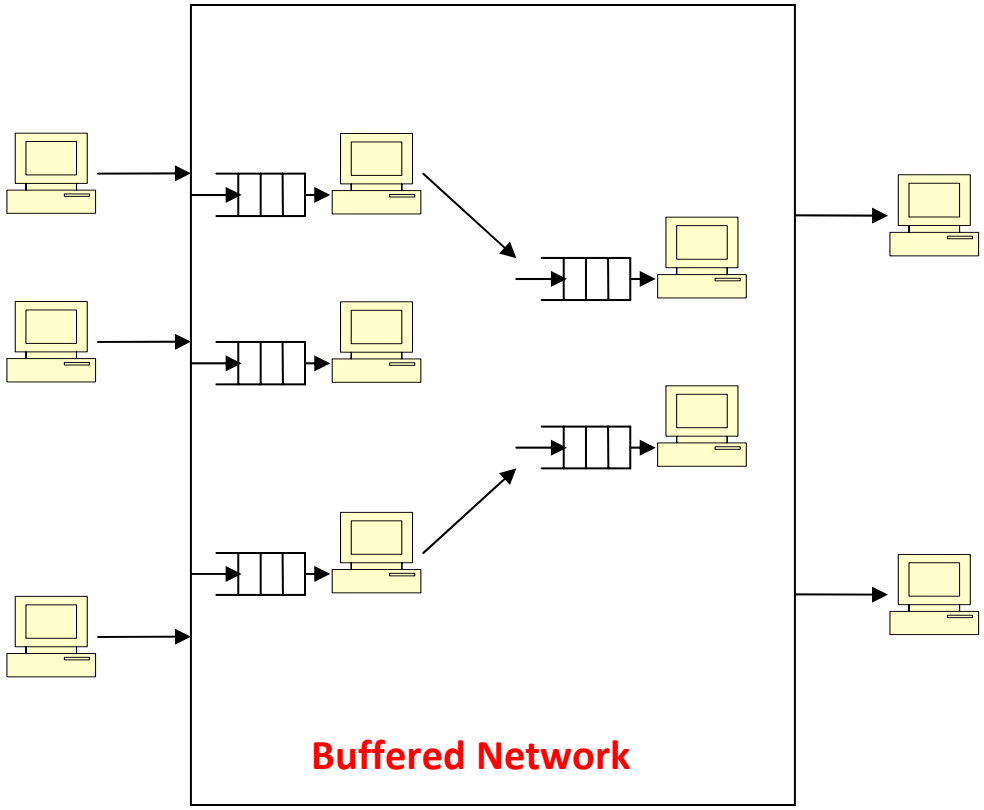
- The electric power grid can be viewed as a typical complex system
  - Large number of interacting entities
  - Dynamical behavior
  - Nonlinear relation
- Therefore, the electric power grid has the same problems as a complex system does
  - Overall behavior is hard to model
  - Small local perturbations could be enlarged and propagated globally.

Internet

- The Internet is also a complex system
  - Billions of users
  - Geographically distributed
  - Highly open
  - Irregular usage patterns
- However, the Internet is surprisingly stable
  - Problems were usually contained locally.
- How?

Storage and Buffer

- Internet adopts a set of protocols to resolve conflicts caused by the competitions over limited resources (bandwidth)
- What make these protocols feasible is the assumption that information transmitted over the network can be **stored and retransmitted**.



Energy Storage

- Similar protocol could be developed for the power grid to
  - resolve conflicts due to the competitions over resources and
  - identify and contain problem locally

  IF electricity can be stored in the grid
- Unfortunately, large scale storage of electricity is technologically and economically infeasible
- Solution: a virtual buffer
  - Electricity can be virtually stored if enough information is gathered and utilized

Virtual Buffer

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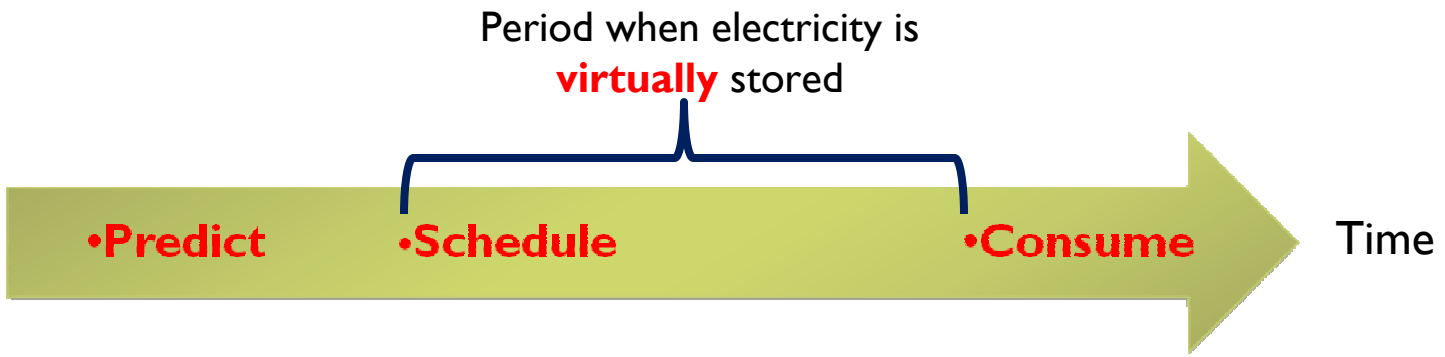
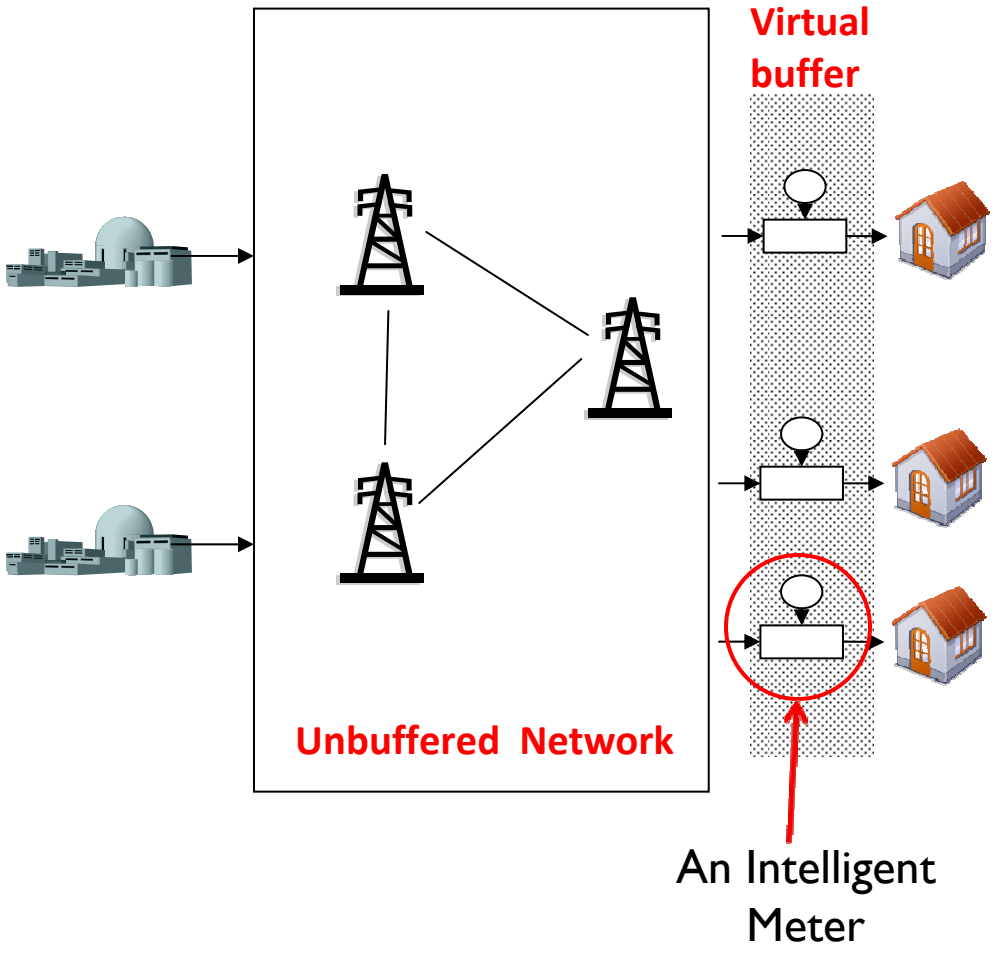
Virtual Buffer: Concepts

- A virtual buffer is built based upon the concept of Dynamical Data Driven Application System (DDDAS)
- The assumption is that electricity demand for an individual customer is predictable
- Based on the demand forecast, the desired amount of electricity is ordered (by an automatic agent on behalf of the customer) ahead of actual consumption
- The supplier receives orders and accept them only if all constraints are met. Otherwise, new (higher) price will be issued to discourage customers from consuming too much electricity
- Price elasticity is used by the supplier to determine the amount of adjustment on price
- Once the order is accepted, from customer's point of view, electricity has been virtually generated and stored



Virtual Buffer: Implementation

- Information can be used to achieve the virtual storage of energy
- Two keys for implementation
  - know electricity demands for individual customers in advance
  - Be able to regulate the demand dynamically
- Hardware
  - An intelligent meter for every customer to handle the planning and ordering automatically
- Algorithms
  - Demand forecast
  - Dynamical regulation via price elasticity



CIMEG and TELOS

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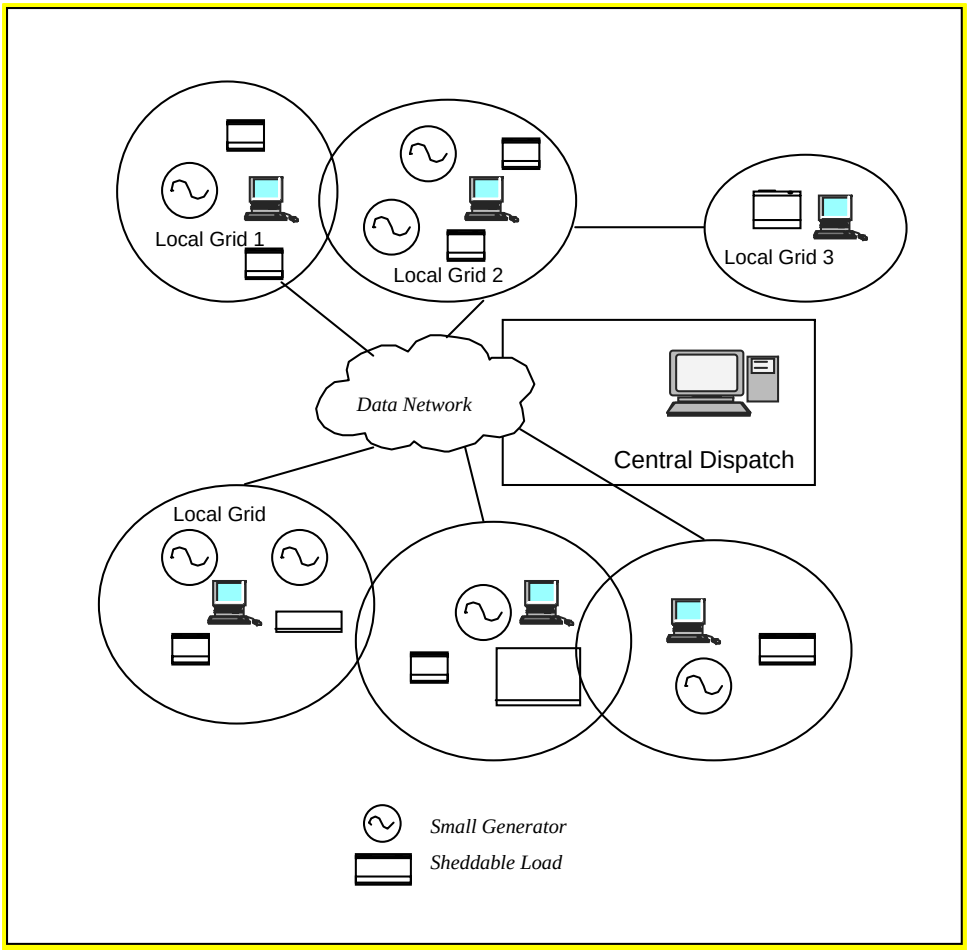
Local Area Grid - LAG

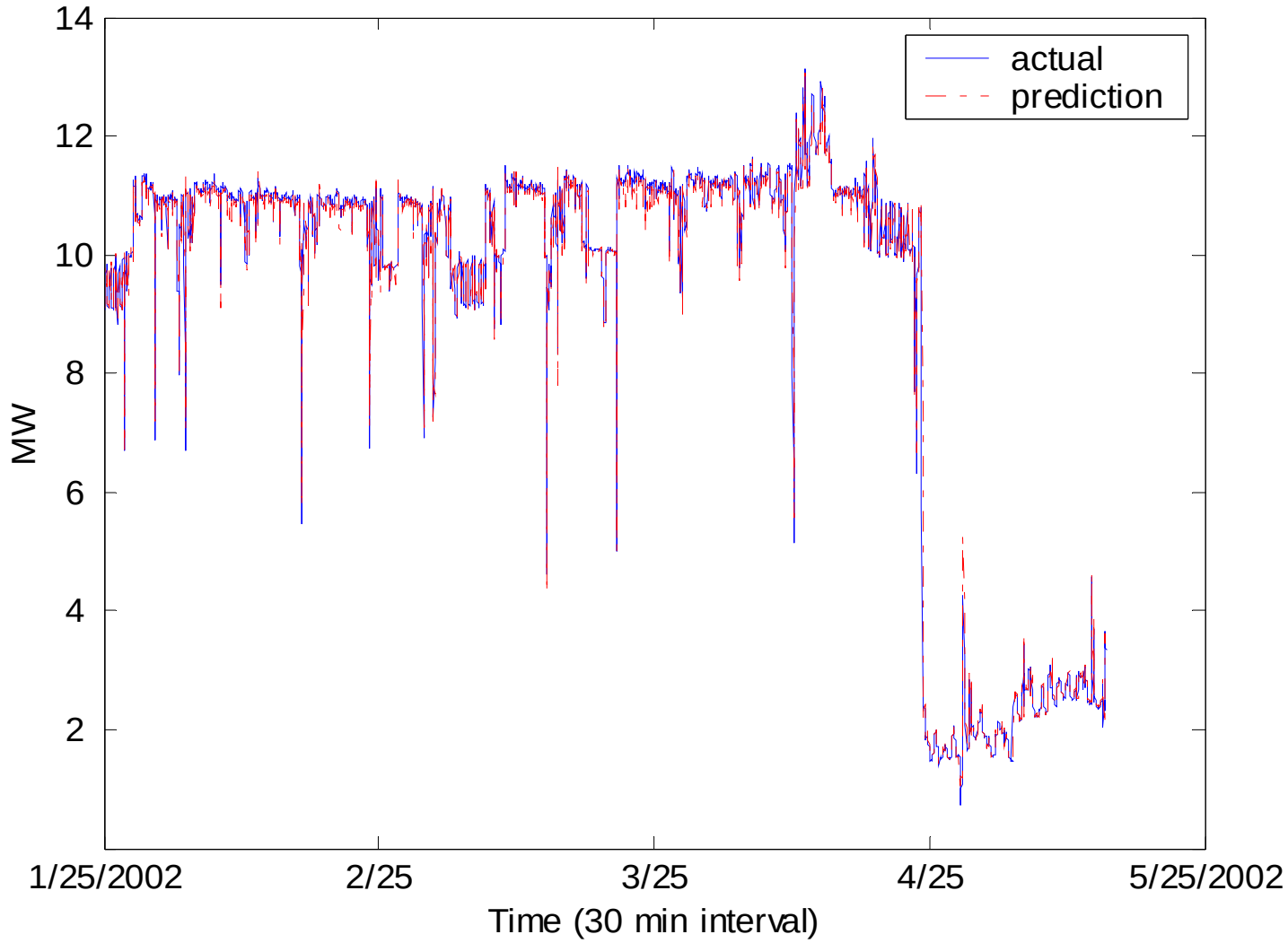
- Defined as a set of power customers
- Power system divided into *Local Area Grids* each with anticipatory strategies for
  - Demand-side management
  - Dispatching small units
  - Energy storage
  - Good neighborly relations



TELOS Design Requirements

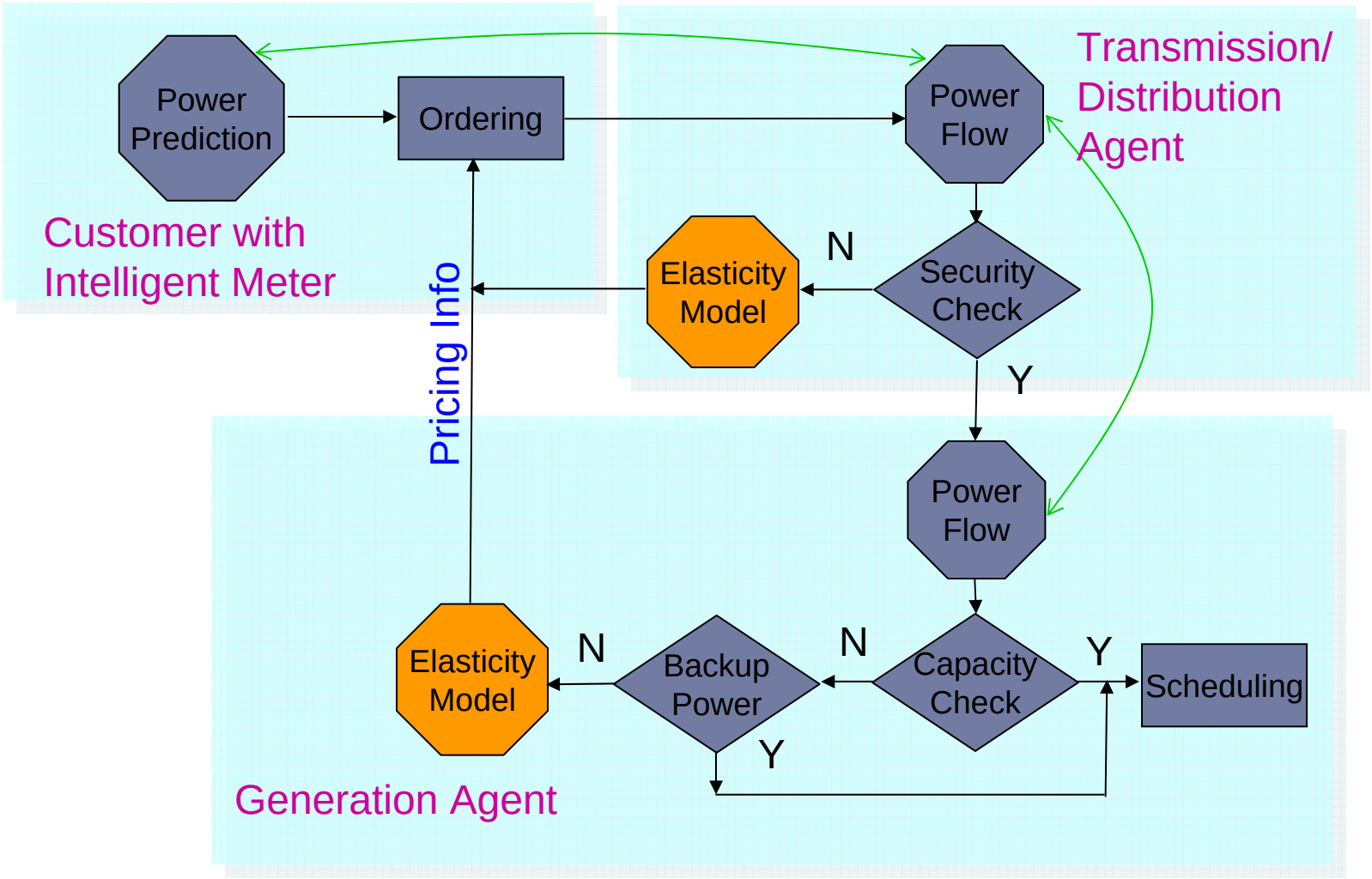
- **TELOS = T**ransmission-distribution **E**ntities with **L**earning and **O**n-line **S**elf-healing
- Local Area Grid (LAG)
- Customer
- System Model
- Power System Calculations
- User Interface
- Automated Execution

Demand Forecast in TELOS



Summary and Conclusions

Dynamical Scheduling via Elasticity



Conclusions

- Information can be gathered and utilized to achieve virtual energy storage in the network
- Virtual buffer allows the development of management protocols to better protect the grid
- Customer-driven approach with anticipatory control is applicable to electrical power grid
- Local Area Grid (LAG) granulizes a complex grid to a manageable level
- Short-term elasticity is an effective tool to regulate electricity consumption
- Intelligent tools make possible elasticity-based strategies

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Xtras

Manage Short-term Elasticity

- Short-term price elasticity characterizes a particular customer's instant responsiveness to the change of price
- Short-term elasticity can be estimated from
  - historical price-demand data
  - psychological model of customers
- The use of intelligent meters is important for
  - Increasing short-term elasticity => more effective for regulation
  - Regulating customers' behavior => more reliable for prediction

Introduction

- Over decades, Purdue research teams have been dedicated to developing methodologies to improve the security and reliability of the electric power grid
- One of our approaches is to use our knowledge about complex systems to better manage the grid
- CIMEG (Consortium for the Intelligent Management of the Electric power Grid) was part of the CINSI (Complex Interactive Networks and Systems Initiative), funded by EPRI and DOD
- TELOS was developed to demonstrate CIMEG's approaches

Price Elasticity

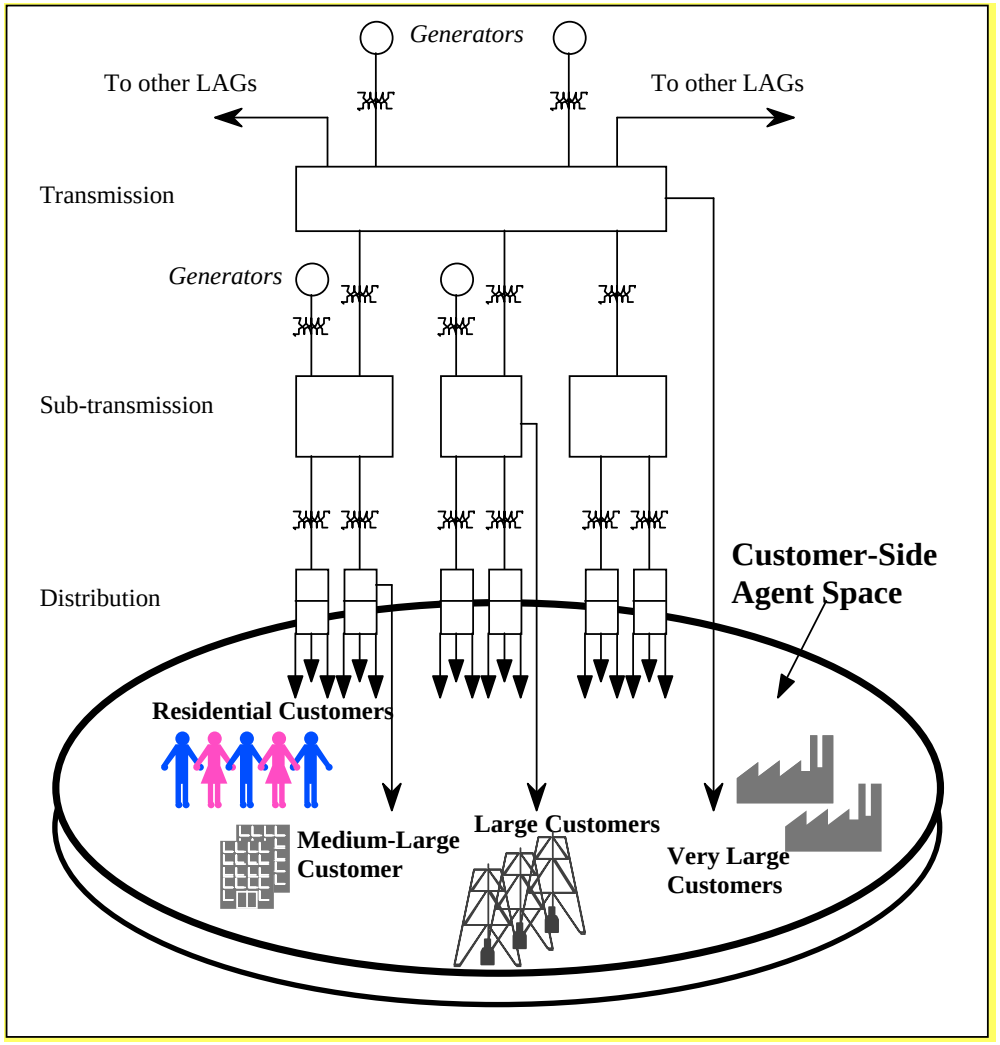
- Elasticity
  - A measure of the degree of responsiveness of one variable to changes in another
  - elasticity = (dY/dX) * X/Y
    - X => Independent Variable (price, incoming, etc.)
    - Y => Dependent Variable (quantity demanded)
- Price Elasticity of Electricity Demand
  - The relative degree of responsiveness of the quantity demanded to relatively small changes in its price

Long- and Short- term Elasticity

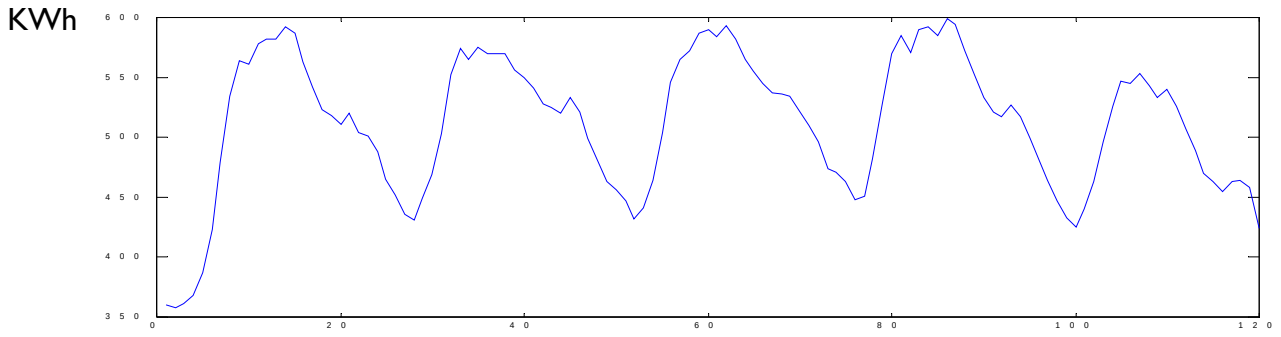
- Long-term Elasticity
  - Average elasticity in within a long period (moths, years)
  - Usually is an overall index including a large number of customers
  - Good for long-run strategic planning
  - More reliable to estimate
- Short-term Elasticity
  - Instant elasticity within a very short period (minutes, hours)
  - Can be a local index for a particular customer
  - Critical for control the power flow
  - Difficult to estimate

CIMEG Approach

- Grid is viewed as polycentric and multilayered system
- Customer-driven
- Grid segmented by groups of customers (LAGs)
- Accurate predictions of nodal demand drive the system
- Optimal dispatch of units (storage)
- *Plug and play* tool: TELOS

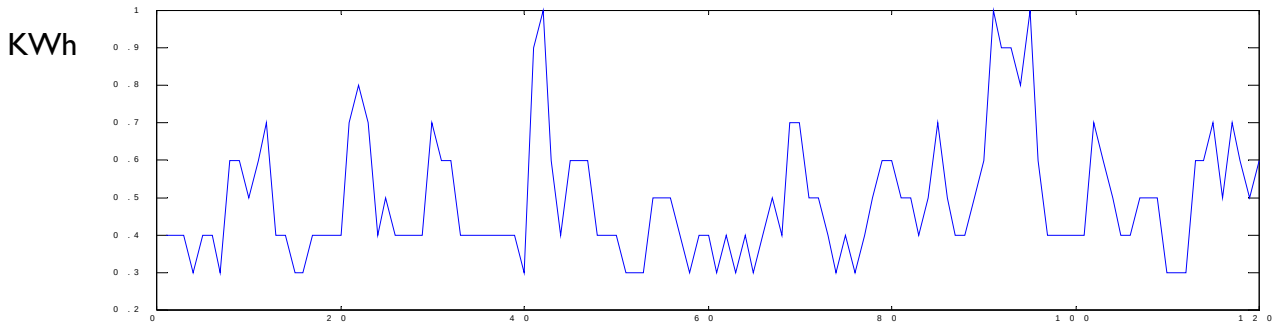


Two Types of Customers in TELOS



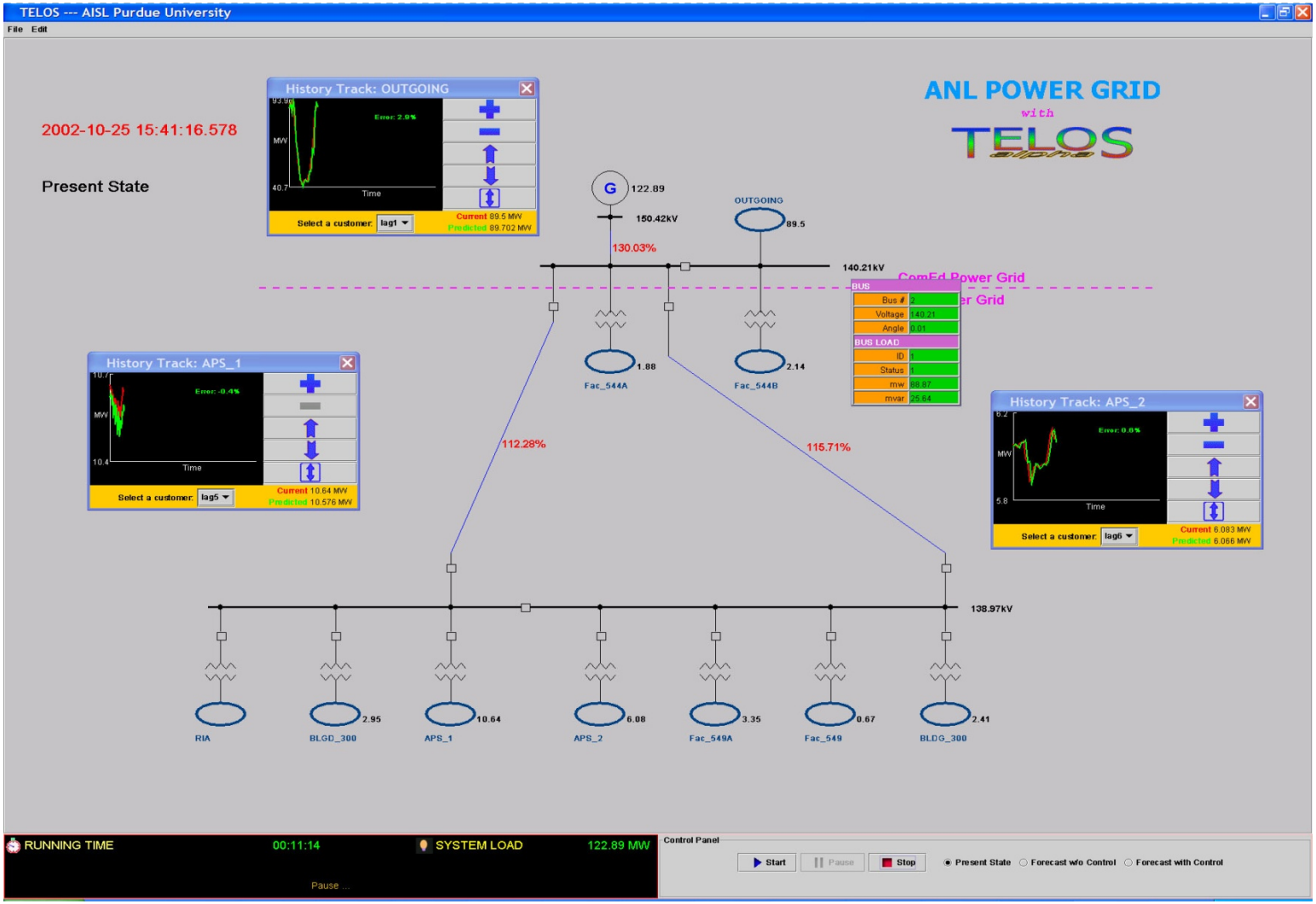
Large Commercial /Industrial (LCI) Customer
Hourly Demand (KW-h) for a week

Hourly data starting at 00:00 Monday



Residential (RSL) Customer
Hourly Demand (KW-h) for a week

TELOS Simulation



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