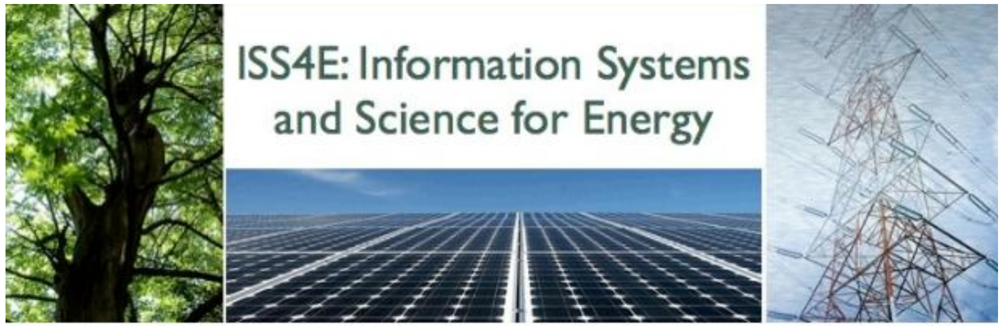
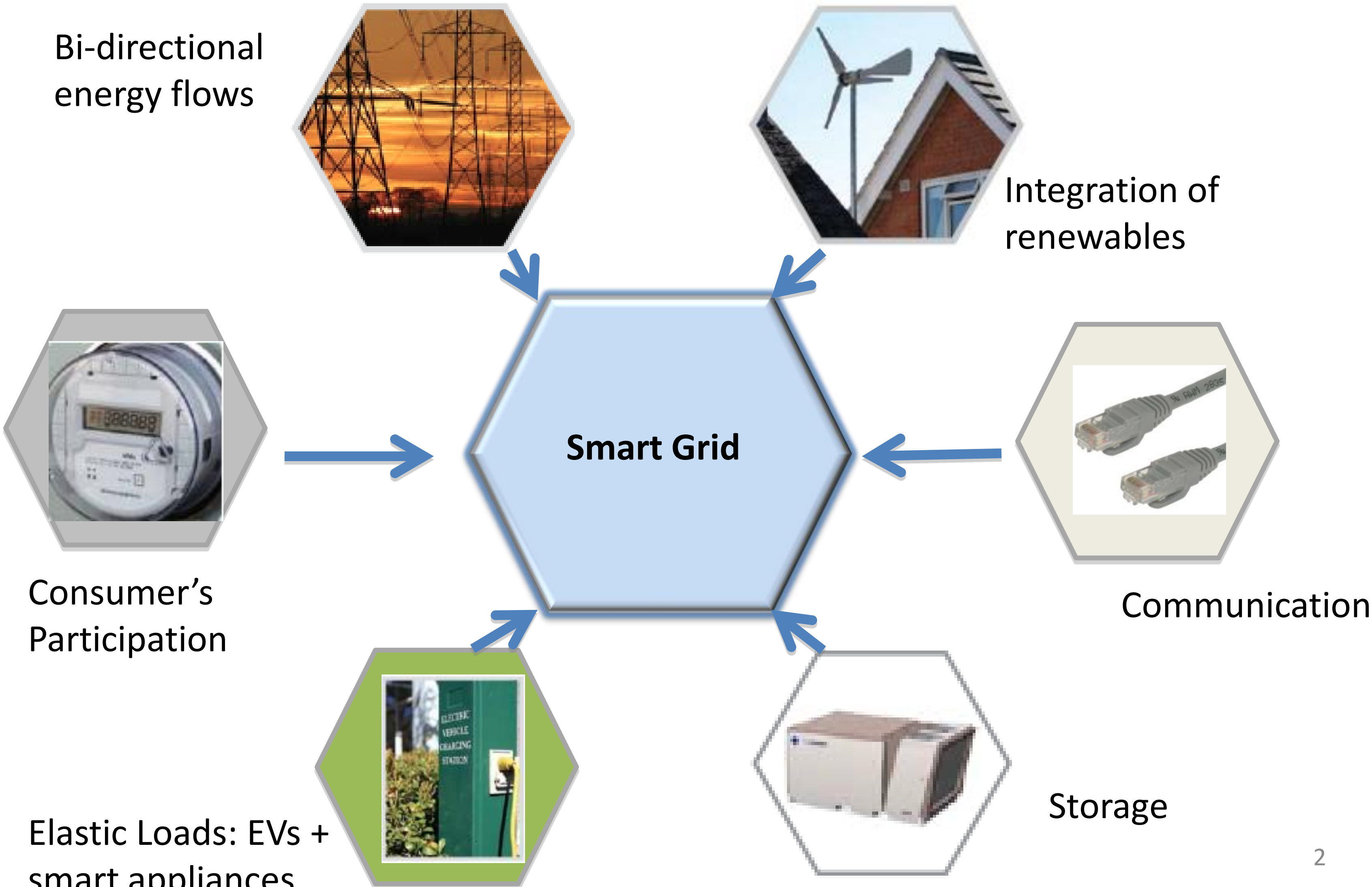



# ISS4E or how can the Internet help smarten the grid.

S. Keshav and C. Rosenberg

April 2011

# Smart Grid


Bi-directional energy flows
Integration of renewables
Consumer's Participation
Smart Grid
Communication
Elastic Loads: EVs + smart appliances
Storage

# Smart Grid: large scale, heterogeneous, distributed system

- Millions of sources
- Stochastic sources
- New loads: elasticity, variable demand
- Two-way flows
- Dealing with storage

- Communication
- Maintaining reliability
- Incentivization
- Security
- Non-traditional utility players

# In a Nutshell

A relatively static, predictable, stable system with inelastic loads and a few points of control

A highly dynamic, unpredictable, potentially unstable system with elastic loads and millions of points of control

**A paradigm shift**

# Our Hypothesis

- It is not enough for our Internet community to:
  - ✓ Reduce electricity use in data centers and telco infrastructure
  - ✓ Use Internet as a communication overlay
- Internet **concepts** can be used to smarten the grid

# Similarities

- Large-scale
- Heterogeneous
- Critical infrastructure
- Both match geographically distributed demands with distributed generation
- Distributed sources that are highly variables
- Simple API

# Similarities

- Hierarchical
  - mesh-like core designed for high capacity
  - tree-like access network
- Balance centralization Tier 1 ISP, TG
  - long-haul transmission
  - generation = data centers
  - strict control
- and decentralization Tier 2 ISP, LDC
  - aggregation
  - customer care
  - loose control

# Differences

- Primarily one-way vs. primarily two-way flows
- Grid has practically no storage
- Consumers are used to see their electrical bill reflect what they really use

# Our proposition: ISS4E

*To apply our expertise in* ***Information Systems and Sciences*** *to find* ***innovative solutions*** *to problems in* ***energy systems***.

*We work in collaboration with*

- *researchers in related disciplines*
- *partners in industry*

***Goal****: have impact both in Canada and around the world*

Initial focus is ***smart grids***, where energy systems converge with information systems

# ISS4E

- **Faculty**
  - S. Keshav, Canada Research Chair, Computer Sciences
  - C. Rosenberg, Canada Research Chair, Electrical & Computer Eng.


- **Post-Doctoral Fellow**
  - Weihong Wang

- **PhD students**
  - Pirathayini Srikantha
  - Tommy Carpenter


- **Masters students**
  - Omid Ardakanian
  - Ryan Case
  - Bo Hu
  - Theodosios Tzoutzas
  - Hadi Zarkoob





- **Laboratory** facilities include sensors for building monitoring, smart power strips for home monitoring and control, ENVI systems for data collection, wireless sensors for solar panel monitoring.

# Our expertise

Modeling, mathematical analysis, and system building using techniques from:

- Internet and information technology (planning, design, implementation, deployment, and management)
- Telecommunications (wireline and wireless communication systems)
- Distributed systems
- Stochastic analysis
- Large-scale simulation
- Data mining and machine learning
- Economics and game theory

# ISS4E and WISE

- The Waterloo Institute for Sustainable Energy (WISE) was established at the University of Waterloo in 2008.
  - Focal point at UW for research in energy studies
- More than 70 faculty members with graduate students and postdoctoral fellows working as multi-disciplinary research teams across Engineering, Science and Environment.
- Research areas:
  - Renewable Energy
  - Storage & Transport
  - Conversion Technologies
  - Emission Management
  - Power System Optimization
  - Sustainable Energy Policy
  - Conservation, Demand Mgmt, Energy Efficiency
  - Green Auto Powertrain
  - ISS4E

# External Collaborators

**Government**

- NSERC
- ORF

**Industry**

- Hydro One
- Waterloo North Hydro
- Technicolor
- IBM (USA, India)
- Infosys (India)
- Microsoft (USA, India)

# Ongoing projects

1. ***Modeling and control of grid energy storage***
2. ***Demand Response: a revisit based on***
   - *Internet views (allows fine grained DR),*
   - *Storage (EV and others),*
   - *DG,*
   - *Elasticity (AP and VP)*
3. ***Smart Home (in collaboration with Infosys and Microsoft)***
   - *GW to appliances (control, measurement)*
   - *Smart UPS*
4. ***Impact of context***
   - *Developed countries*
   - *Developing countries*
5. ***Tools***
   - *Simulation*
   - *Measurements: ENVIs, Sensors, I-smart*
   - *Prototypes*

# DR: our vision

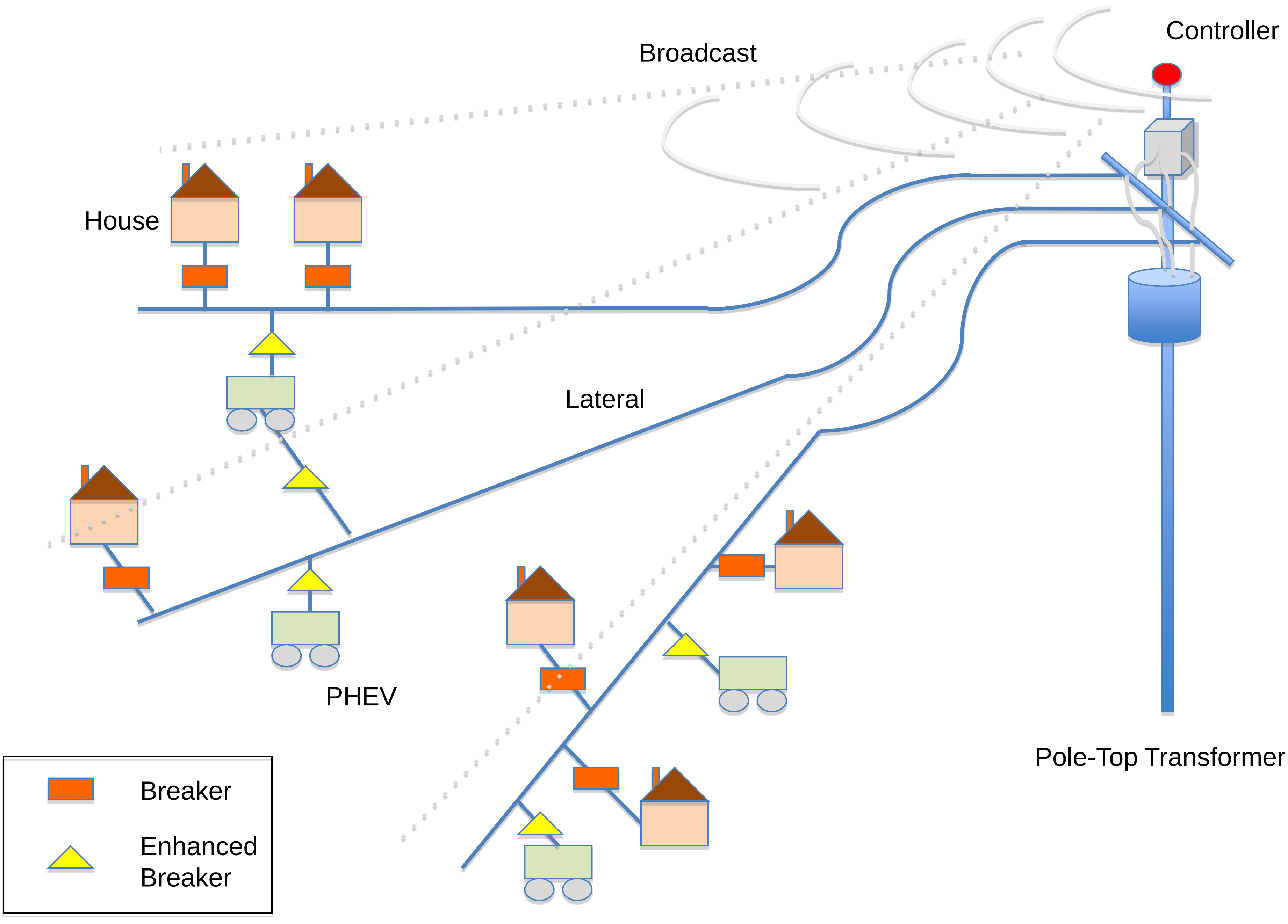
- Radically different approach to DR
- Port principles from congestion control in the Internet to the Electric Grid
  - Fine-grained
  - Stable
  - Efficient
- Incorporate storage, EVs, elastic loads and distributed generation

# DR: our vision

- Notion of elasticity:
  - Changing the load profile by time shifting or varying power consumption is possible for some appliances
- Three types of loads:
  - Constant power (aka CBR)
    - Lighting
  - Variable power (aka VBR)
    - AC, heaters, refrigerators
  - Available power (aka ABR)
    - EV

# DR: our vision

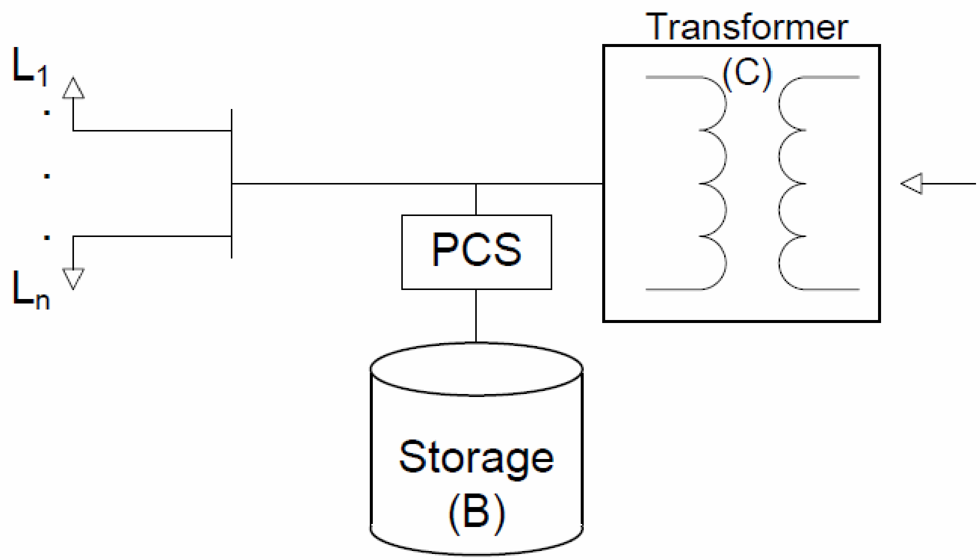
- Example of an elastic load: battery in a PHEV
  - Participation in DR is compulsory to access higher level charging
  - Charging rate can be varied at a fine time-scale
  - Charging time can be shifted
  - Users will not be affected as long as the battery is charged next day
- If there is some ‘capacity’ available in the lateral, battery can be charged
  - At a higher rate when load from inelastic appliances are low and vice versa
- A solution based on explicit rate notification and rates are computed to avoid phase unbalance
- Simulation under way using GridLab D


Broadcast
Controller
House
Lateral
PHEV
Pole-Top Transformer
Breaker
Enhanced Breaker

# Sizing the Electrical Grid

- We prove a formal equivalence between transformers and storage in the grid and routers and buffers in a network, allowing us to use teletraffic theory to analyse the grid
- We provide design rules for provisioning storage in the grid and study the insights gained from these rules
- We show that sizing decisions made using our design rules compares well with the 'ground truth' sizing obtained by directly measuring loads and, moreover, can lead to gains over existing sizing techniques

# The System




(a) A branch of the electrical grid with $n$ loads $L_i$ where the capacity of the battery is $B$ Watt-hours and the base rating of the transformer is $C$ Volt Amperes. The Power Conversion System (PCS) drains and fill the store depending on load conditions.

- Easy to show that this system is equivalent to a *D/G/1/B* queue for which we want to compute the underflow probability $P_0$.
- Sizing this system is equivalent to find all the pairs (C, B) such that $P_0$<LOLP (loss of load probability)

# Equivalence Theorem

- Our system is equivalent in trajectory to a *G/D/1/B* for which we want to compute the overflow probability $P_B$
- Hence, under the right assumptions, we can reuse asymptotic results on effective bandwidth

# Results and Validation

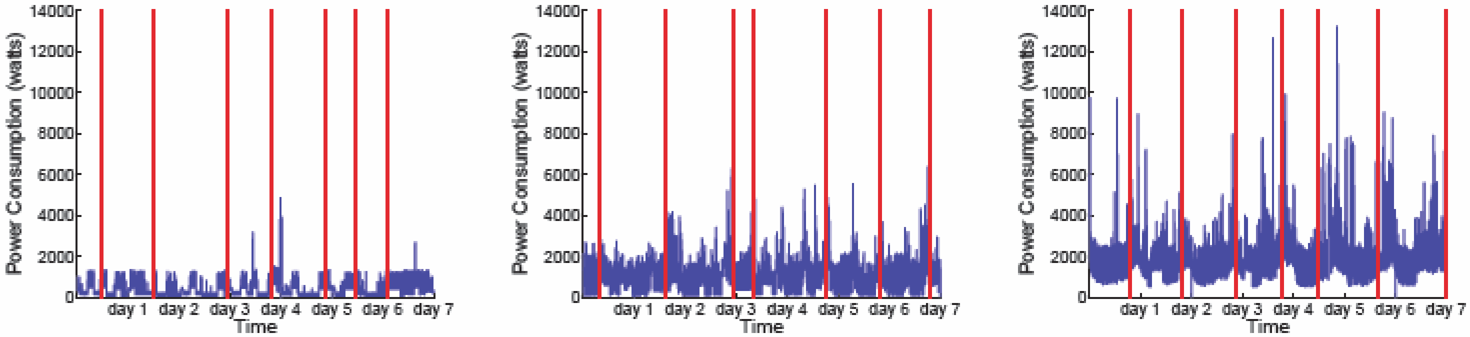
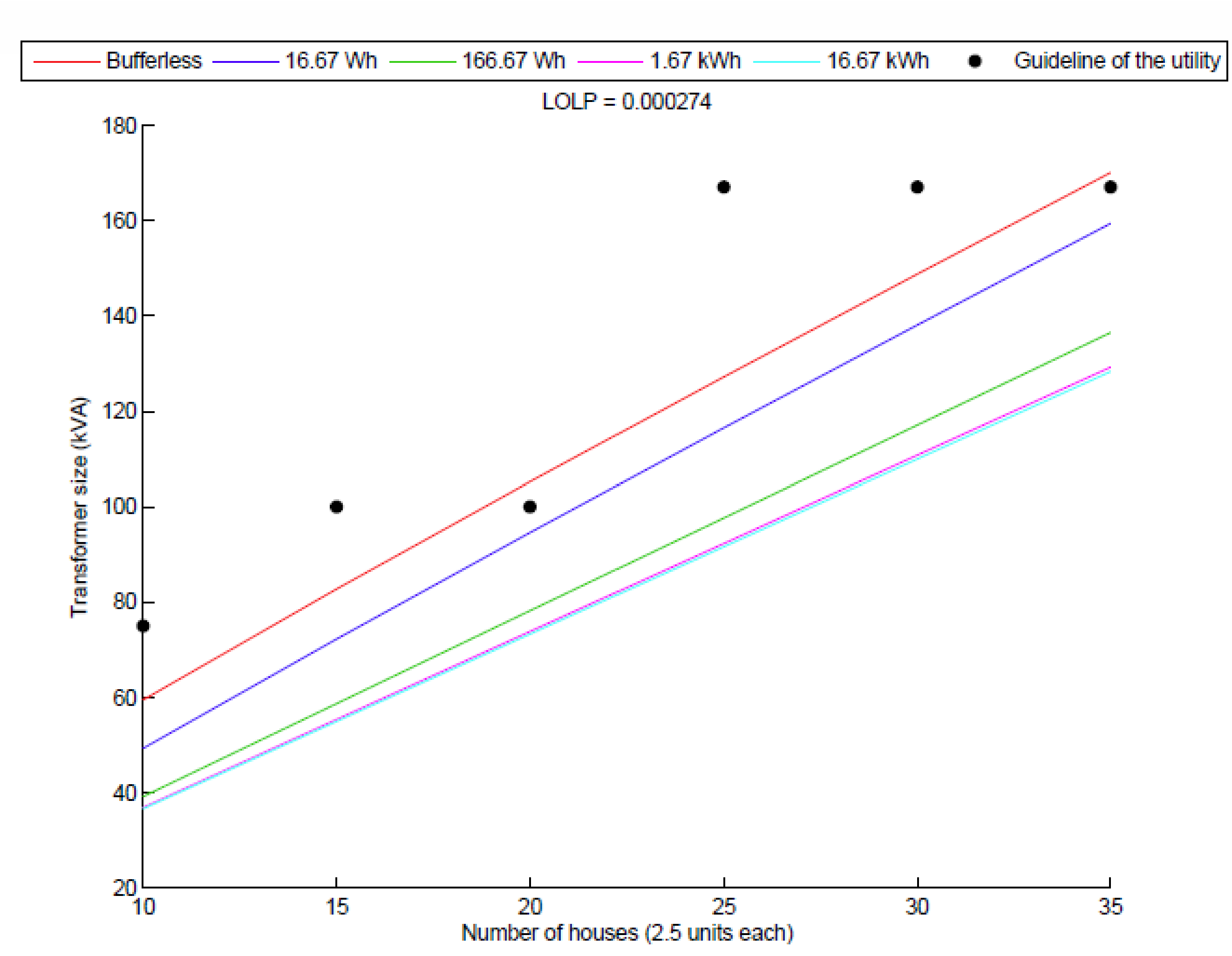



Figure 3: Load measurements from houses in three classes for one week with busy hours marked by vertical lines.

# Results and Validation



# Conclusions

- 2010-2020 will decide the grid of 2120
- Internet $\approx$ Grid
- 40 years of Internet research {could, should, may} help
- Rich area for impactful research