Towards an intelligent future energy grid

15 Sep 2016

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Current Research & Educational Services at the School of EIE

- EIE has been providing research and educational services in the following areas
- Advanced sensor technology
- Big data and computer networks
- Defence technology
- Fibre networks
- Next generation telco technologies
- Smart grid technologies
- Renewable energy
- Biomedical engineering

Contents

From power systems to energy internet

- Quick overview of energy systems research
- The road map of energy systems R&D and industry development
  - Power systems
  - Smart grid
  - Future grid/energy internet
- Opportunities and challenges

Power Engineering Research

- Existing Expertise
  - Power system modelling, including load modelling
  - Power system security assessment (deterministic & probabilistic)
  - Power system economic dispatch
  - Power system planning
  - Demand side management/control, energy storage
  - Dynamic line rating
  - Electricity market modelling, generation planning and risk management
  - Smart grid – modelling, control, power quality, PV, DG and BESS
  - Wind power modeling, forecasting, oeperations and grid connection impact studies
  - Generator grid connection
  - Load and price forecasting
  - Grid/Parallel/Cloud computing and data mining for power system analysis
- Strategic (new) direction:
  - condition monitoring
- Research Partners/Funding Sources:
  - ARC, CSIRO, TNSPs, DNSPs, AEMO, EPRI, SG, SCSG, HEC, CEM, CLP, …

Smart grid research projects

- A Data-Driven Intelligent Distribution System for Smart Grid
- Dynamic line rating in a smart grid
- Distributed forecasting.
- Knowledge discovery from system measurement data.
- Distribution Network Reconfiguration.
- Volt VAR Planning and Real-Time Control
- Real Time Measurement Data Based Dynamic Line Rating
- Modelling, Analysis and Networked Control of Smart Distribution Grids
- Wide area composite coordination of frequency regulation strategy in Smart Grids
- Autonomous Decentralized Systems
- Grid Computing Platform for Power System Stability Assessment.
- Wind power prediction, planning and wind farm impact on system stability.
- Smart grid (cyber) security & vulnerability modelling tool and assessment algorithms
- Future grid
- Load modelling

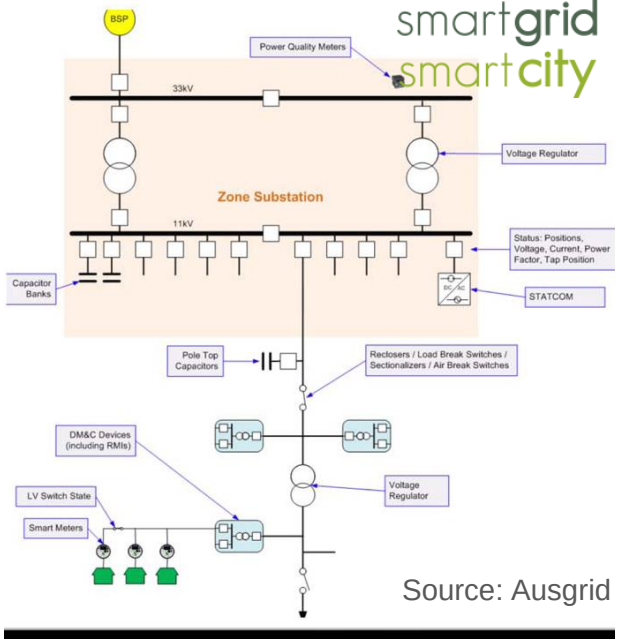
Power system control & reliability and telco

Peak demand & reliability

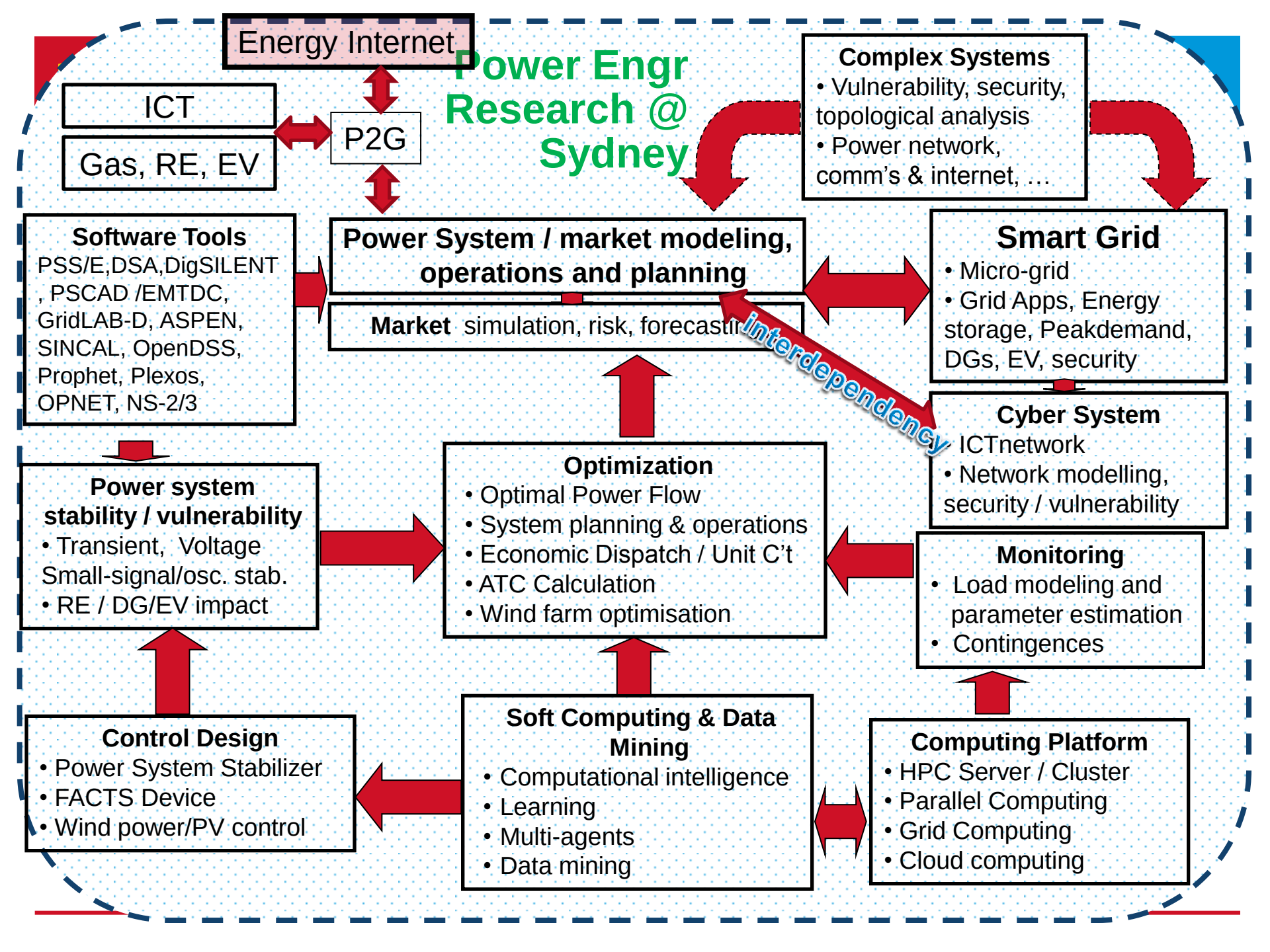
Market / financial / investment efficiency

environment

smartgrid smartcity

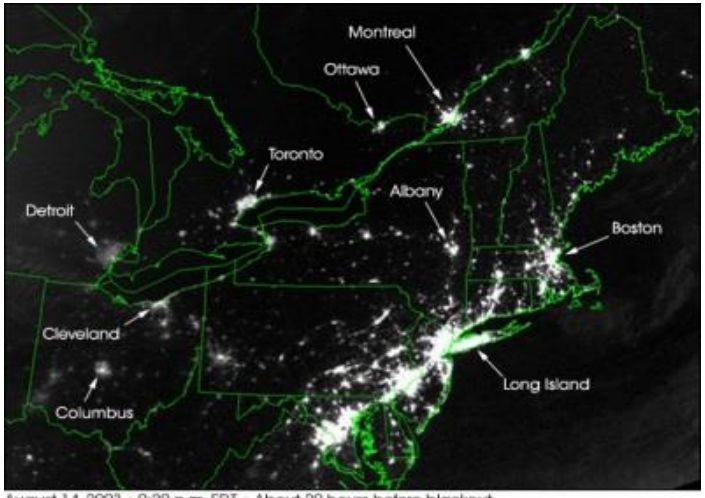


Source: Ausgrid

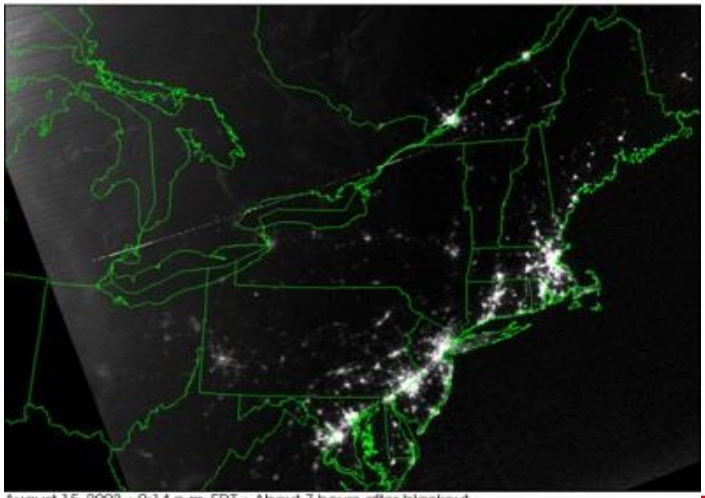

Energy Internet
Power Engr Research @ Sydney
ICT
Gas, RE, EV
P2G
Complex Systems
• Vulnerability, security, topological analysis
• Power network, comm's & internet, …
Software Tools
PSS/E,DSA,DigSILENT , PSCAD /EMTDC, GridLAB-D, ASPEN, SINCAL, OpenDSS, Prophet, Plexos, OPNET, NS-2/3
Power System / market modeling, operations and planning
Market simulation, risk, forecasting
Smart Grid
• Micro-grid
• Grid Apps, Energy storage, Peakdemand, DGs, EV, security
Interdependency
Cyber System
• ICTnetwork
• Network modelling, security / vulnerability
Power system stability / vulnerability
• Transient, Voltage Small-signal/osc. stab.
• RE / DG/EV impact
Optimization
• Optimal Power Flow
• System planning & operations
• Economic Dispatch / Unit C't
• ATC Calculation
• Wind farm optimisation
Monitoring
• Load modeling and parameter estimation
• Contingences
Control Design
• Power System Stabilizer
• FACTS Device
• Wind power/PV control
Soft Computing & Data Mining
• Computational intelligence
• Learning
• Multi-agents
• Data mining
Computing Platform
• HPC Server / Cluster
• Parallel Computing
• Grid Computing
• Cloud computing

1. Road Map of Power Engineering

Power system/smart/future grid – monitoring, measurement, modelling, control, security, telecommunications, power, computing, electronics, computing, regulation, situational awareness … …



August 14, 2003 • 9:29 p.m. EDT • About 20 hours before blackout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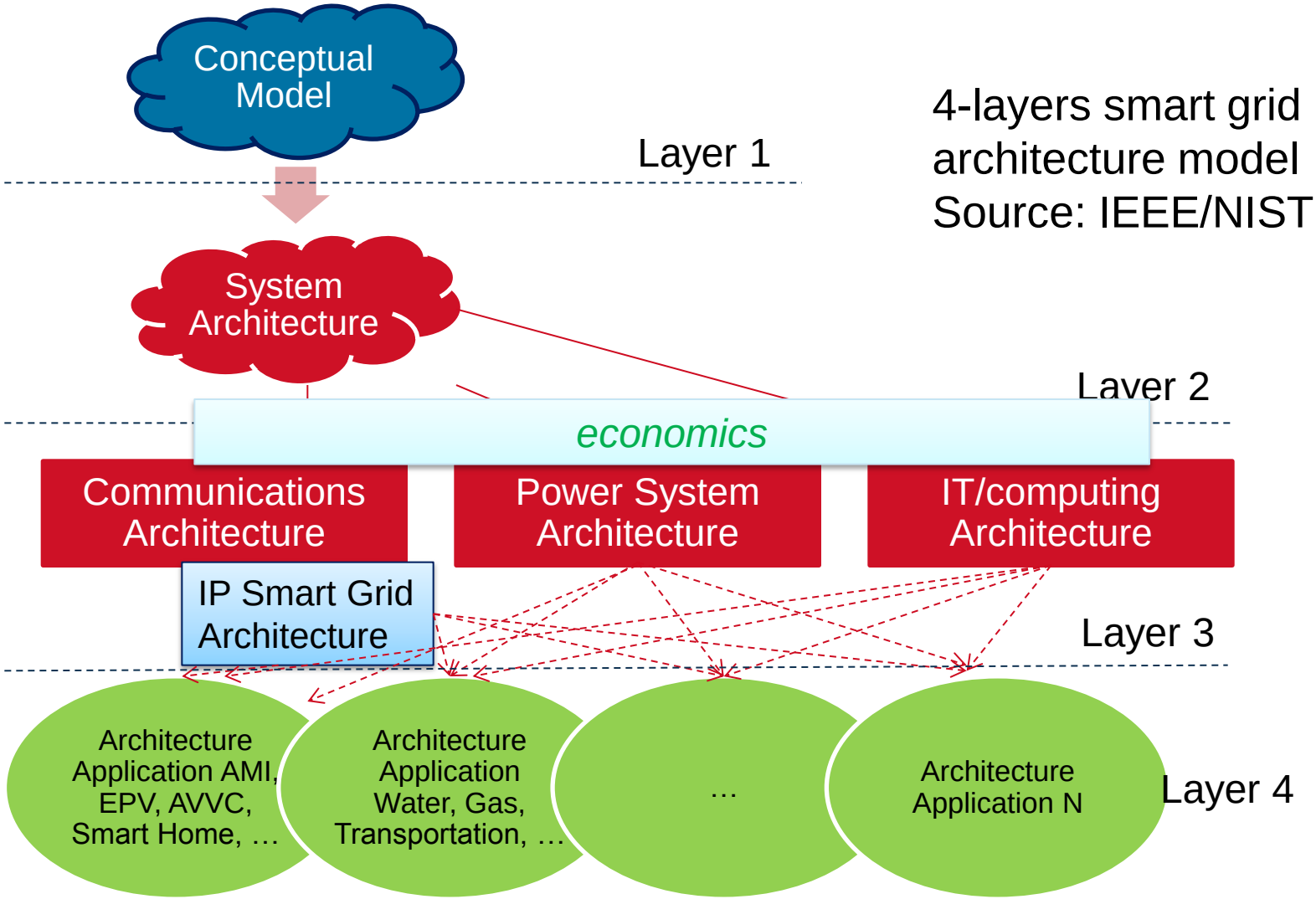
grid → Smart grid → Future grid → Energy Internet

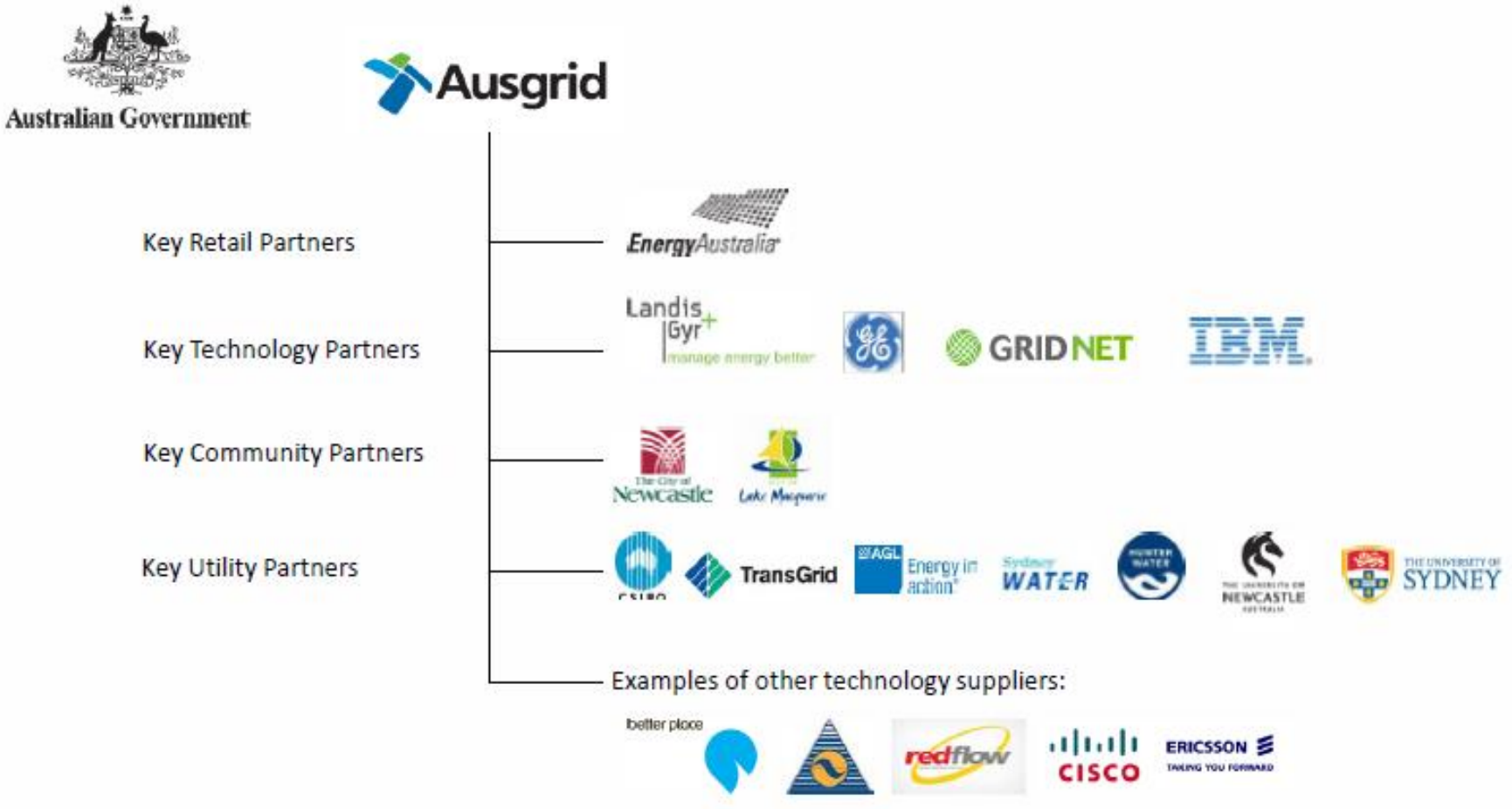
2. Smart Grid



4-layers smart grid architecture model
Source: IEEE/NIST

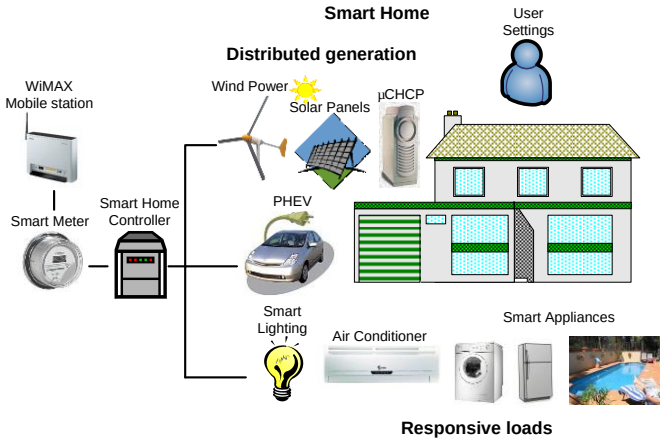
Smart Grid Smart City

Partners



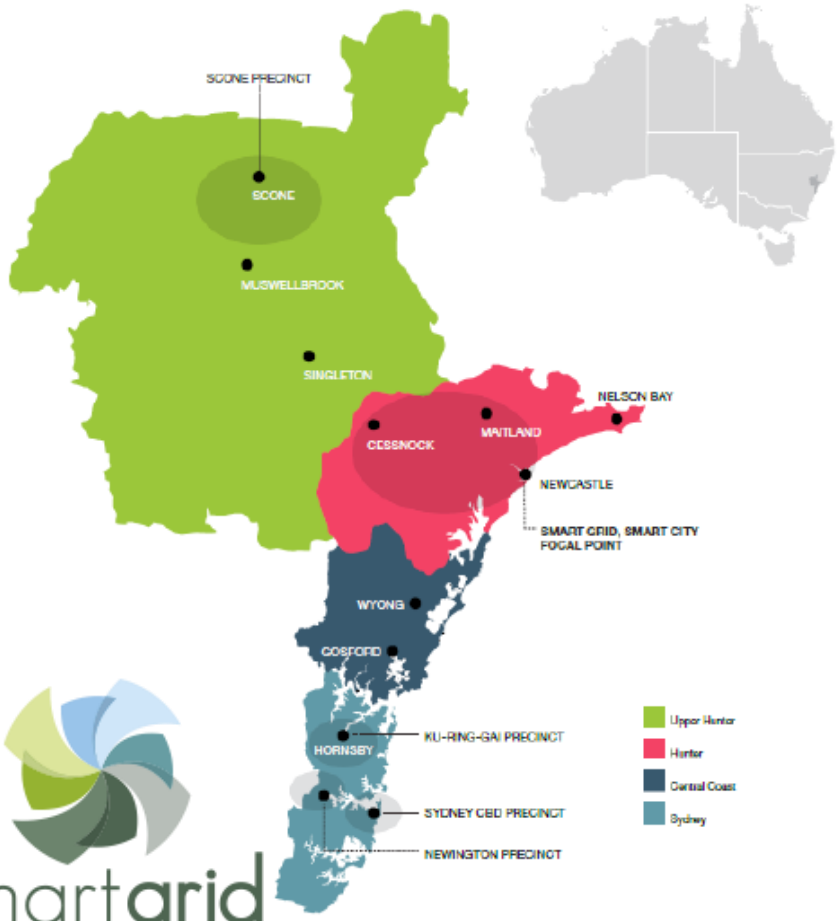
Smart Grid Applications

1. Customer Applications
2. Active Voltage & Power Factor Correction
3. Distributed Storage
4. Fault Detection, Isolation & Restoration
5. Electric Vehicle Support
6. Substation & Feeder Monitoring
7. Wide Area Measurement
8. Distributed Generation Support
9. Interoperability with other Utilities & the NBN



Smart Grid Smart City Leadership

An $100M Commonwealth Government Initiative



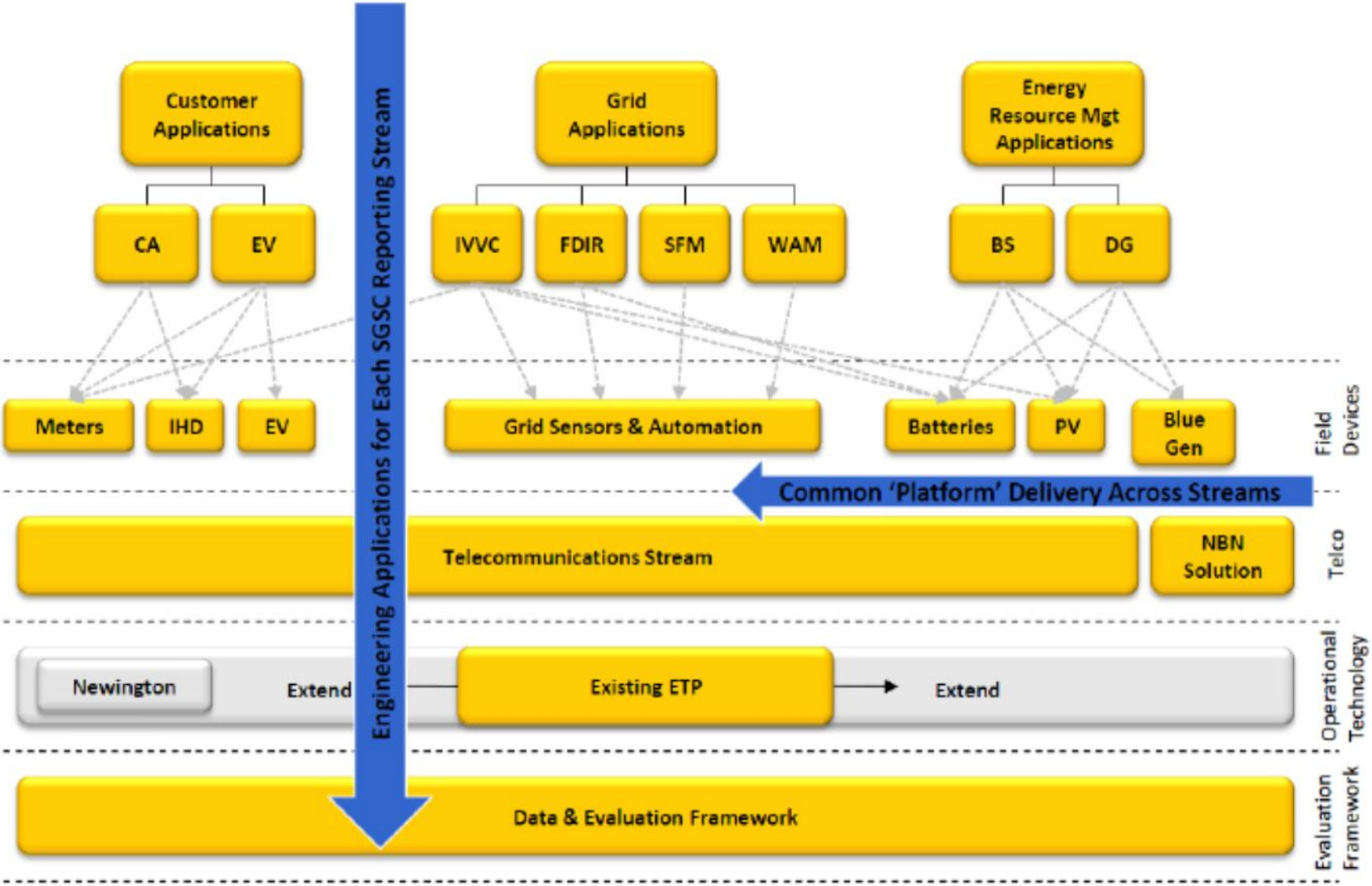
smartgrid smartcity

One of the largest commercial-scale trail deployments of smart grid infrastructure in the world

$600m

The University of Sydney to host the SGSC Information Clearing House containing key datasets and results

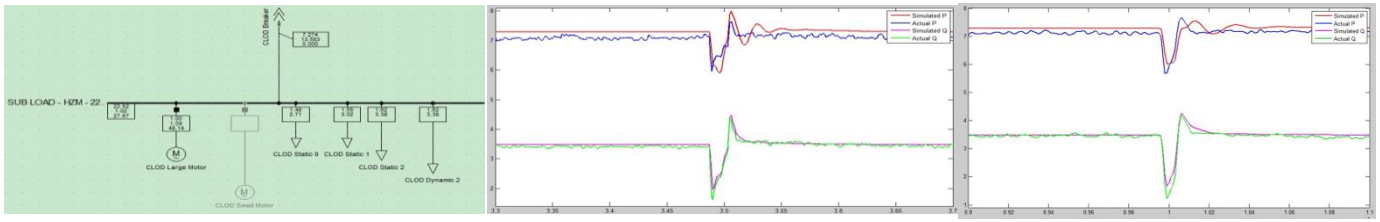
Smart Grid Smart City Applications



Load Modelling (load model parameter identification & generalisation)

- Research Problems:
  - Different values of parameters describe different dynamic properties of load model.
  - using different dynamic response data in the task of parameter identification will obtain different parameter values.
  - how the real dynamic properties of load model can be reflected by the appropriate selection of load model parameters.
  - Specific measurement based load modelling, PSS_E, DigSILENT

- Support: EPRI, ARC, HKPU, SG/EPRI, Western Power Corp, AEMO, StatGrid
- CIGRE C4.605: Modelling and Aggregation of Loads in Flexible Power Networks
- We developed the system model for Western Power Corp, AEMO, Ausgrid and AEMO; the models are currently be used by clients

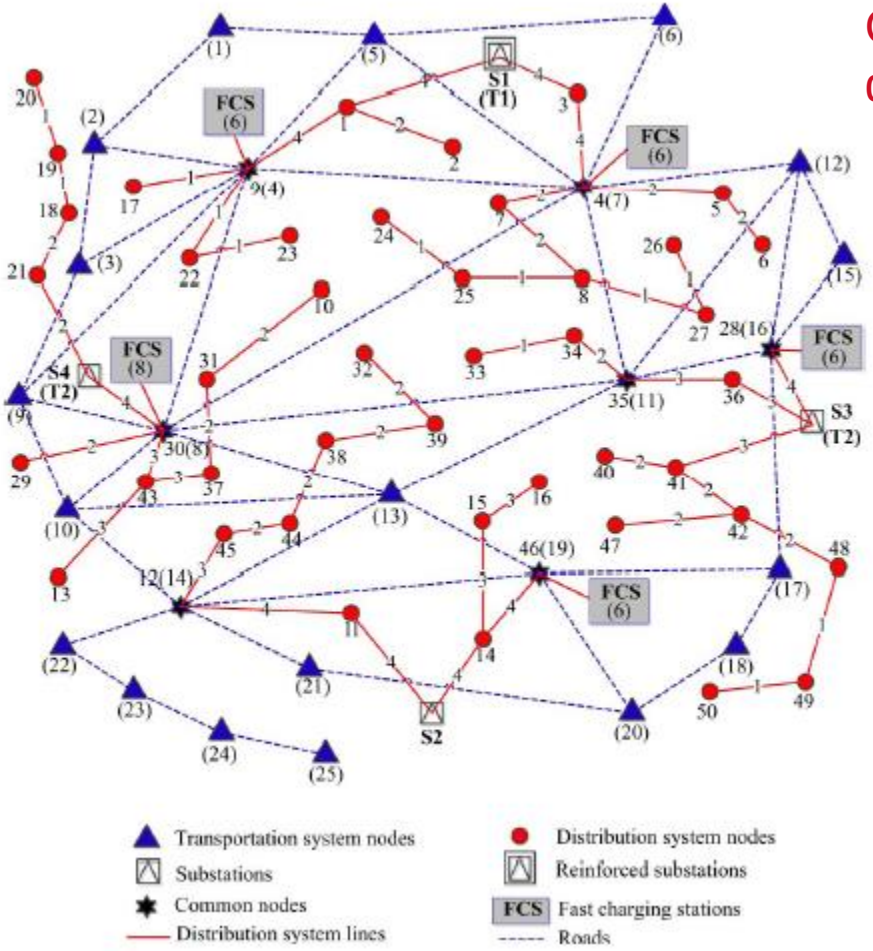


Trial Objectives

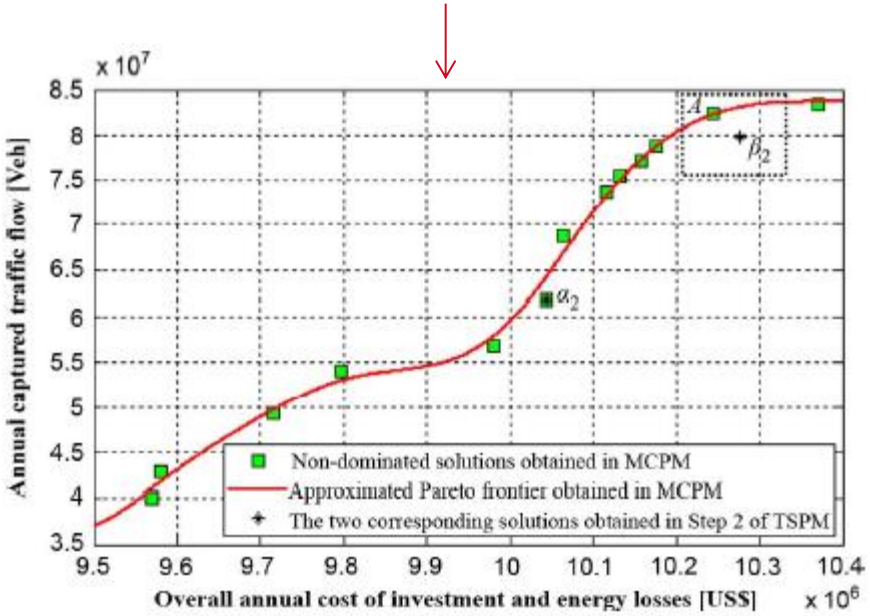
- The battery is planned to be connected through a four quadrant inverter and to be used for a variety of trials including:
  - Distributed Generation enetration Impact;
  - Network Peak Demand Reduction;
  - Wholesale Energy Price Optimisation; and
  - Voltage Regulation.
- The specific objective of this study is to investigate:
  - What is the correlation between the demand and the PV generation on a feeder
  - What is the correlation between the voltage and the PV generation on a feeder
  - What are the upstream impacts of existing PV systems?

Electric Vehicle

Co-planning of EV charging stations and distribution stations



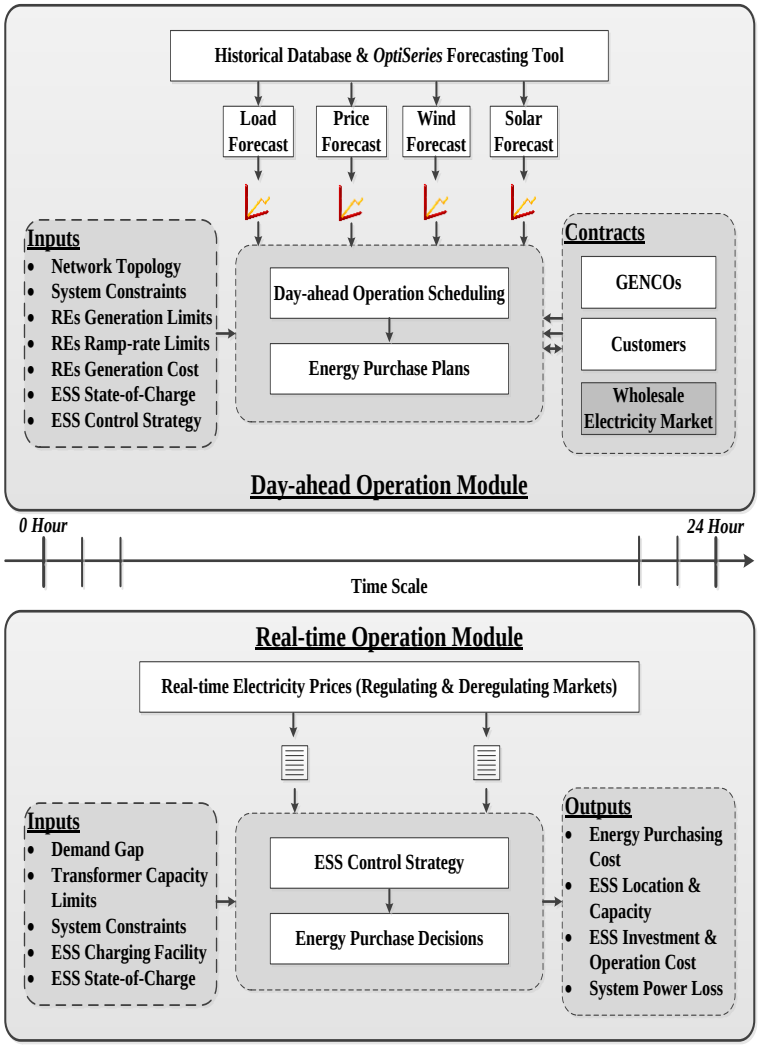
Multi-objective decision-making

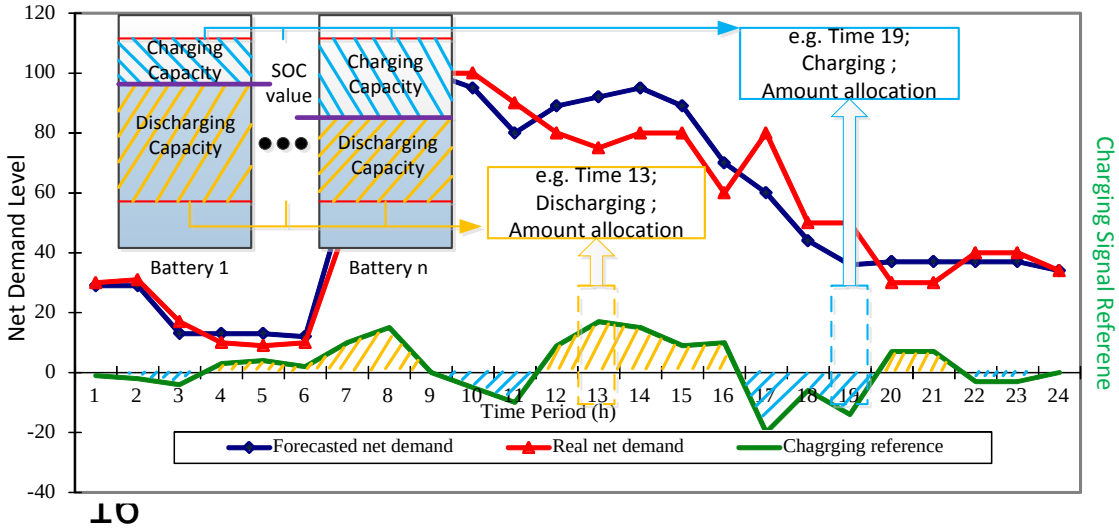


W. Yao, J. Zhao, F. Wen, Z.Y. Dong, Y. Xue, Y. Xu, and K. Meng, "A multi-objective collaborative planning strategy for integrated power distribution and electric vehicle charging systems," *IEEE Trans. Power Systems*, vol. 29, no.4, pp. 1811-1821, Jul. 2014.

DISCO risk management with ESS

- Based on forecast, DISCOs may save significant energy purchasing cost and reduce risks from a volatile real-time market by adjusting the operational modes of ESS.
- With the advent of ESS, the real-time load gap can be compensated to mitigate the high penalty cost or spinning reserve price



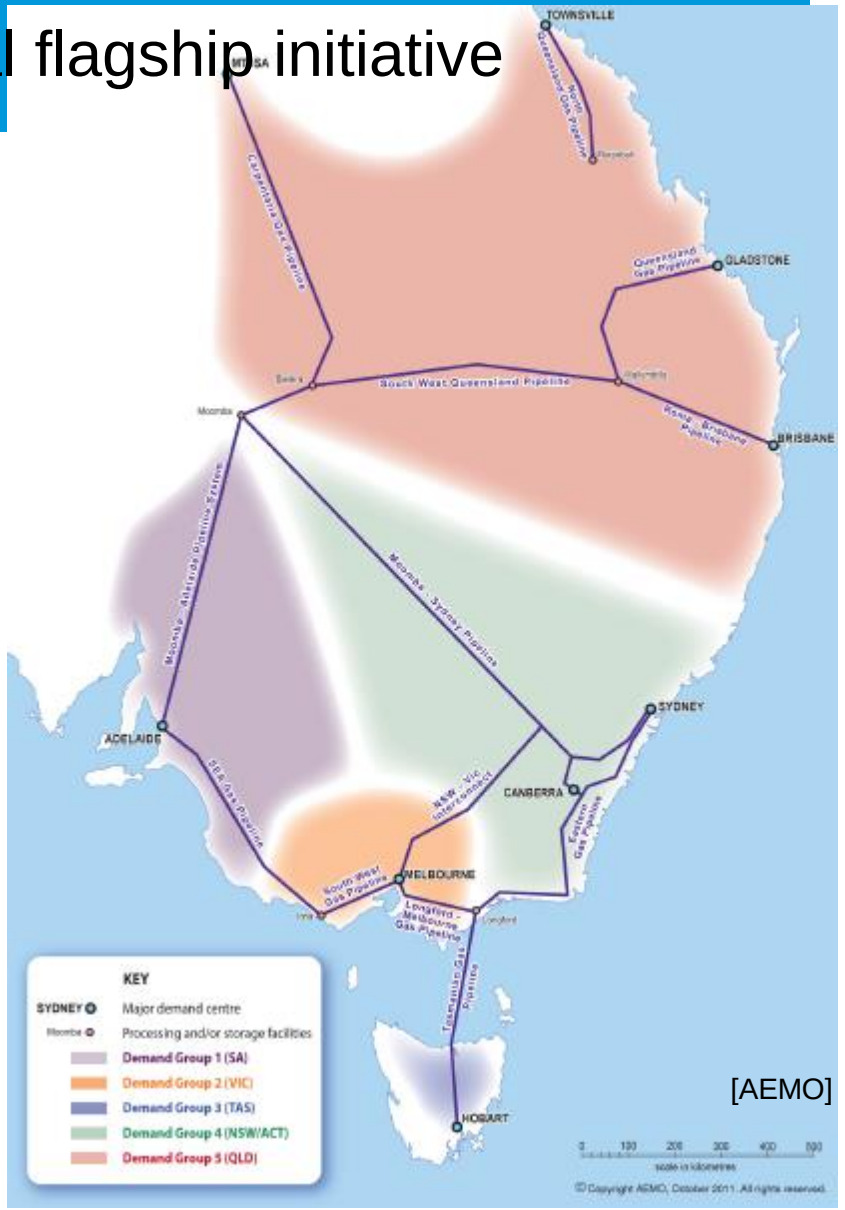


Source: Y Zheng, ZY Dong et al, "Optimal allocation of energy storage system for risk mitigation of DISCOs with high renewable penetrations", IEEE Trans Power Systems, (accepted to appear) 2013

Future Grid – a national flagship initiative

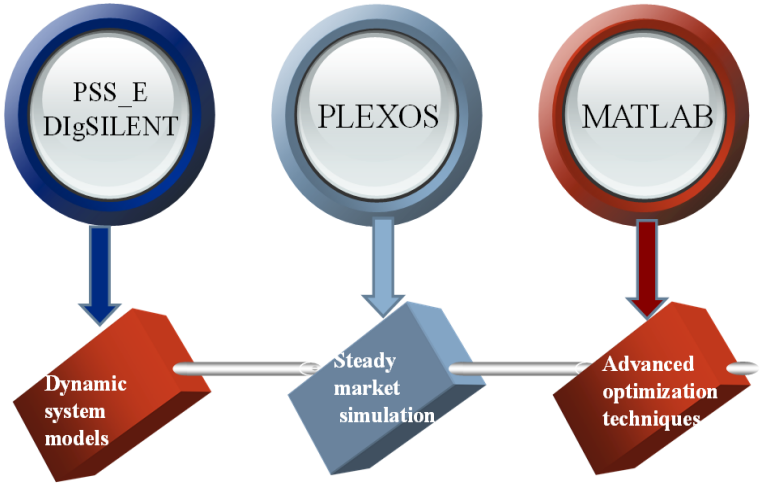
To achieve benefit maximisation, we need to include both transmission and distribution system, plus gas network → Future Grid

- Power and Energy Systems Modelling and Security
- Grid Planning and Co-optimisation
- Economic and Investment Models for Future Grids
- Robust energy policy frameworks for investment in the future grid

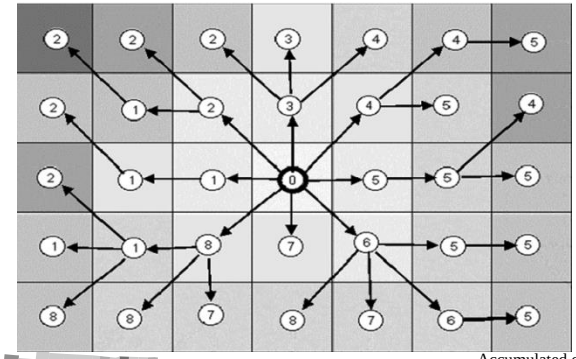


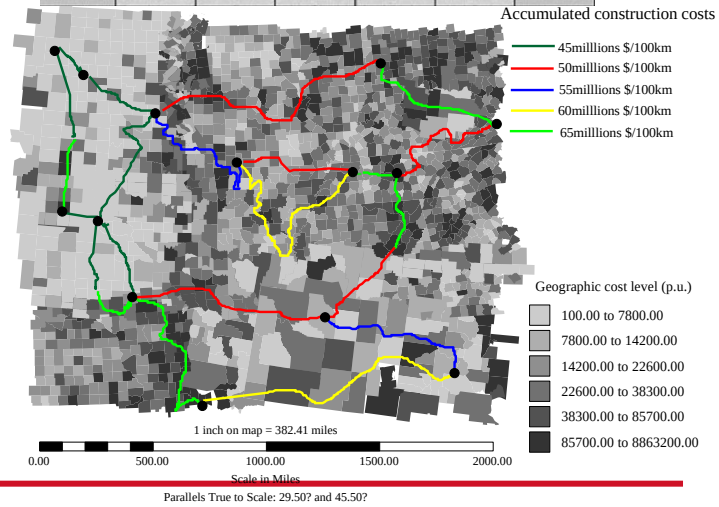
[AEMO]

Future Grid



GIS-based implementation tool





PSS_E & DIgSILENT

- Dynamic power system simulation
- Small signal and eigenvalue analysis
- Optimal power flow
- Short circuit calculations
- Balanced and unbalanced fault analysis
- Deterministic and probabilistic contingency analysis
- Transient stability studies
- Voltage stability analysis
- Assessing impacts of geomagnetic induced currents

PLEXOS

- Market analysis and design
- Electricity price and gas price forecasting
- Capacity expansion planning
- Generation and transmission asset evaluation
- Transmission analysis and congestion management
- Renewables integration analysis
- Portfolio optimization
- Gas modelling
- Risk management
- Fuel and emission constraint management
- Bid information and trading decision support

MATLAB

- Game-theoretic simulations
- Variance reduction technique
- Distributed computing technique
- Mathematical optimization (mixed-integer programming, iterative algorithm, network flow programming, analytic hierarchy approach, branch and bound, Benders decomposition, Lagrangian relaxation, etc.)
- Heuristic optimization (artificial immune system, genetic algorithm, fuzzy-sets, simulated annealing, expert systems, differential evolution, particle swarm optimization, etc)

Energy Internet - Current Development

USA - FREEDM (Future Renewable Electric Energy Delivery and Management)

http://www.freedm.ncsu.edu/

secured communication, distributed grid intelligence, high-frequency and high-voltage power conversion, and distributed energy storage devices

2012 - Vice President Tajani called for a comprehensive Third Industrial Revolution ... “This Third Industrial Revolution is the **internet of energy** and is not only about energy. …”

E-Energy – the Internet of Energy

ICT system concepts that **optimize entire** electricity supply system – generation, transport to distribution and consumption

http://www.e-energy.de/en/12.php

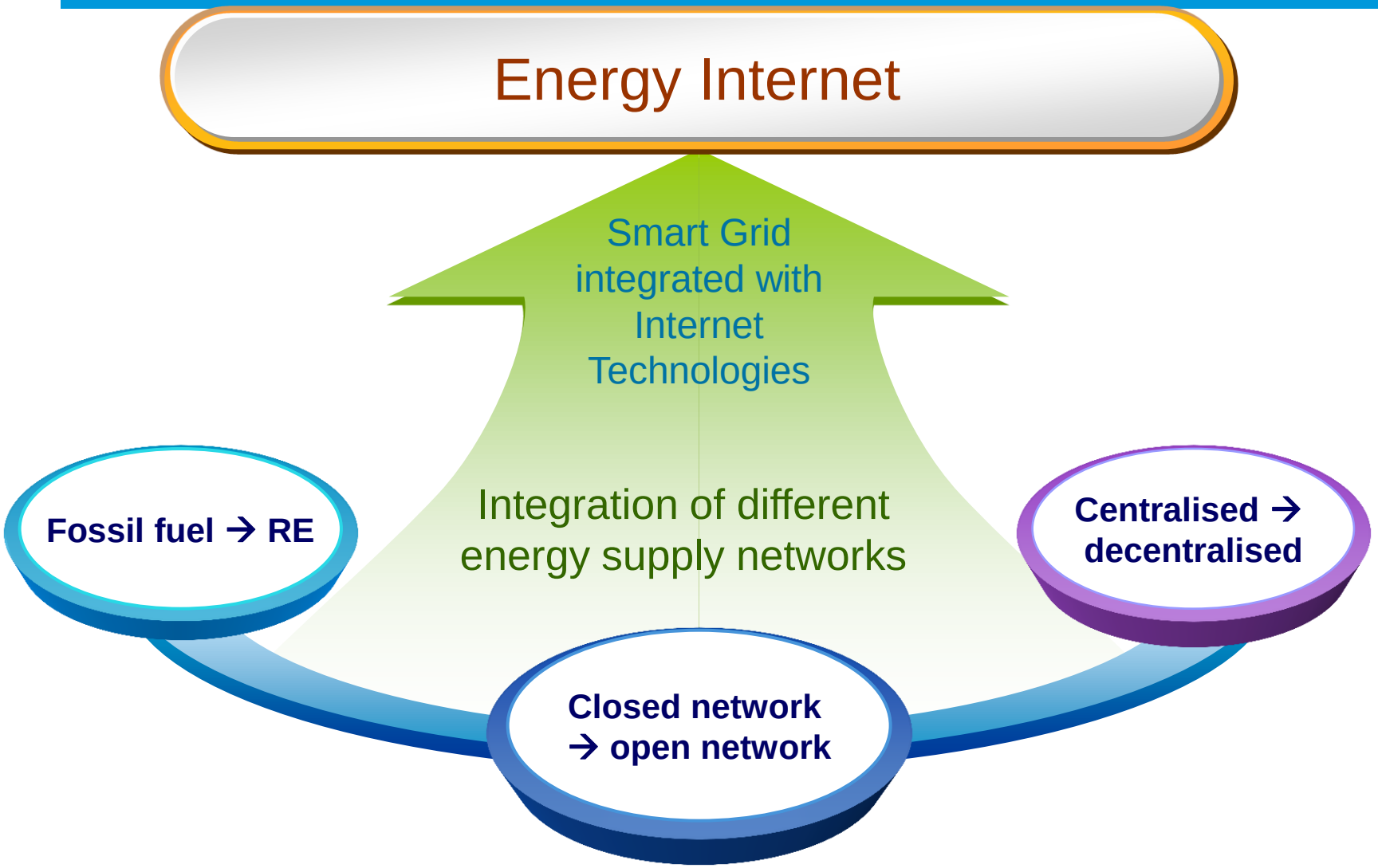
Energy Internet - Overview

Energy Internet = smart grid + other energy networks (e.g. gas) based on next generation ICT technologies

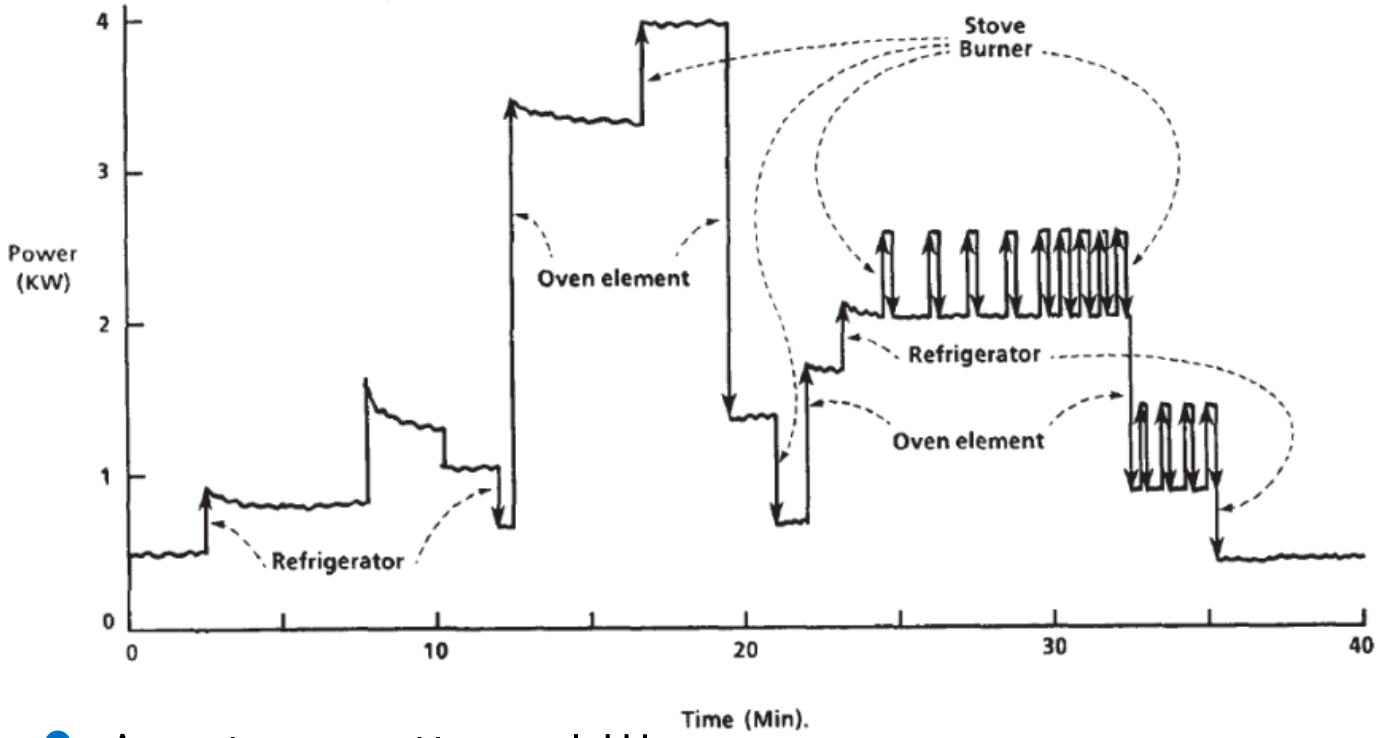
3 Key Components of an Energy Internet

1. **Wide area power grid internet and energy coordination and management**
2. **Multiple energy conversion and integration**
3. **Next generation internet based big data analytics, prosumer management**

Smart Grid → Energy Internet



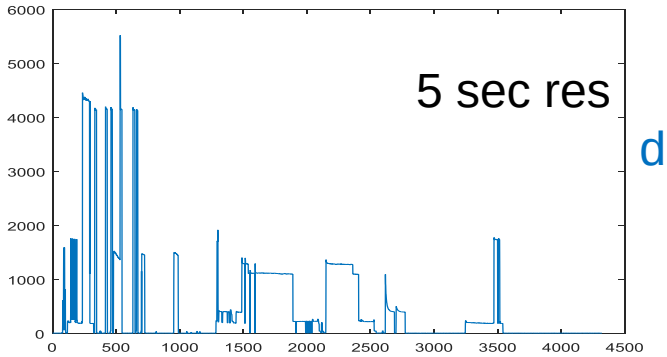
Eg. High frequency appliance level data analytics



- Accurate user pattern modelling
- Detailed load prediction (rigid, interrupt-able, shift-able loads) Time varying flexible load modeling
- Time varying load modelling with multiple data source and cross-checkable approach

Can smart meter be smarter?

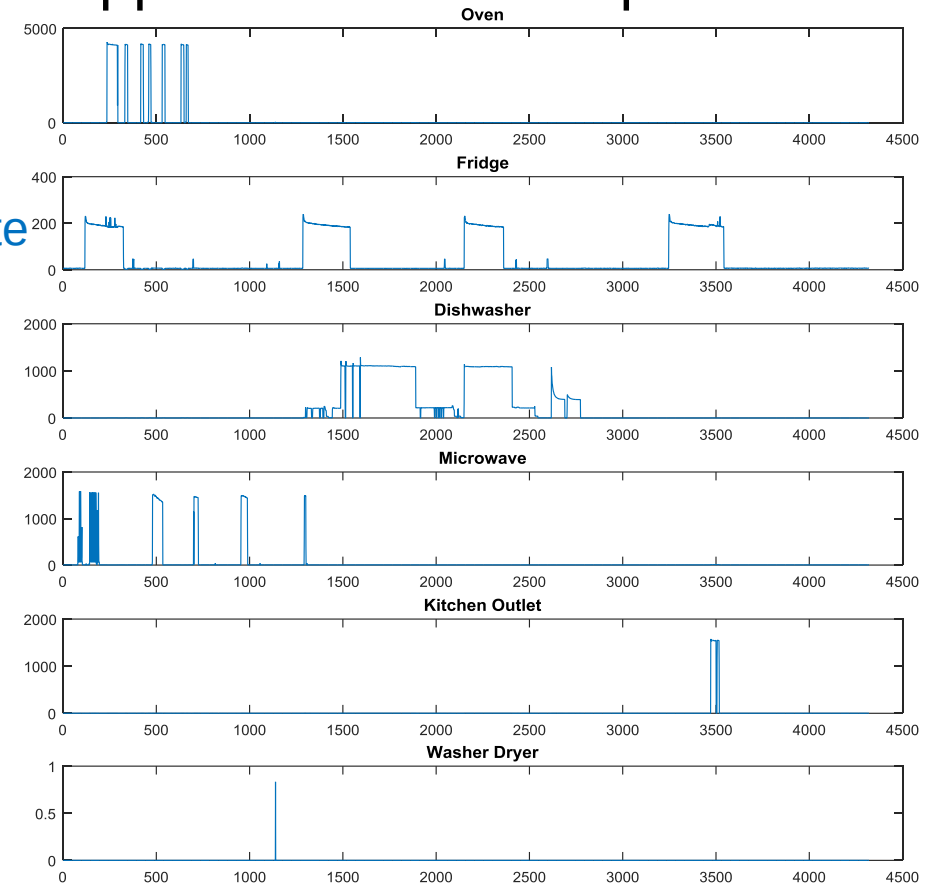
Aggregated Profile



disaggregate

Smart Meter

Appliance-wise load profile

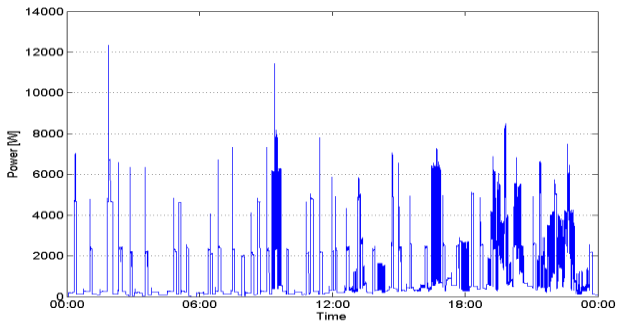


Non-Intrusive Load Monitoring (NILM)

Facilitate Smart Grid Tech: Demand Response

Non-Intrusive Load Monitoring (NILM)

Aggregated Profile



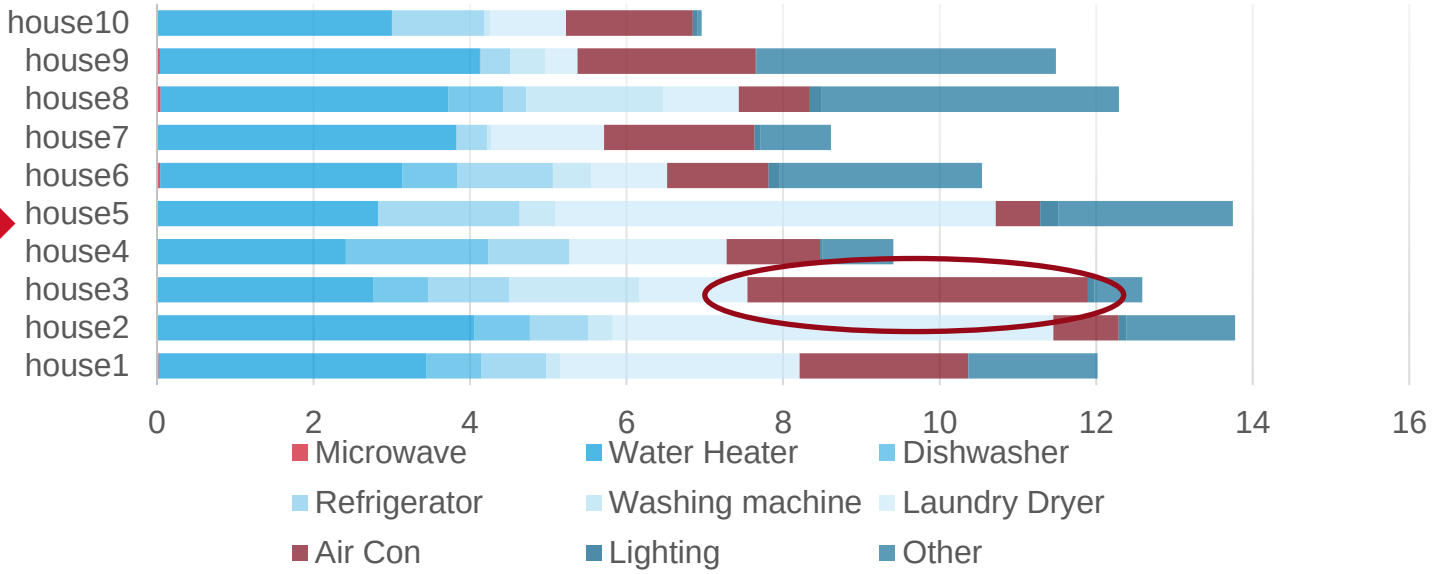
- Break the aggregated load profile down to device-level profiles
- DR potential differs among appliances
- Allows dynamic assessment of DR performance/potential

Smart Meter

High DR Potential

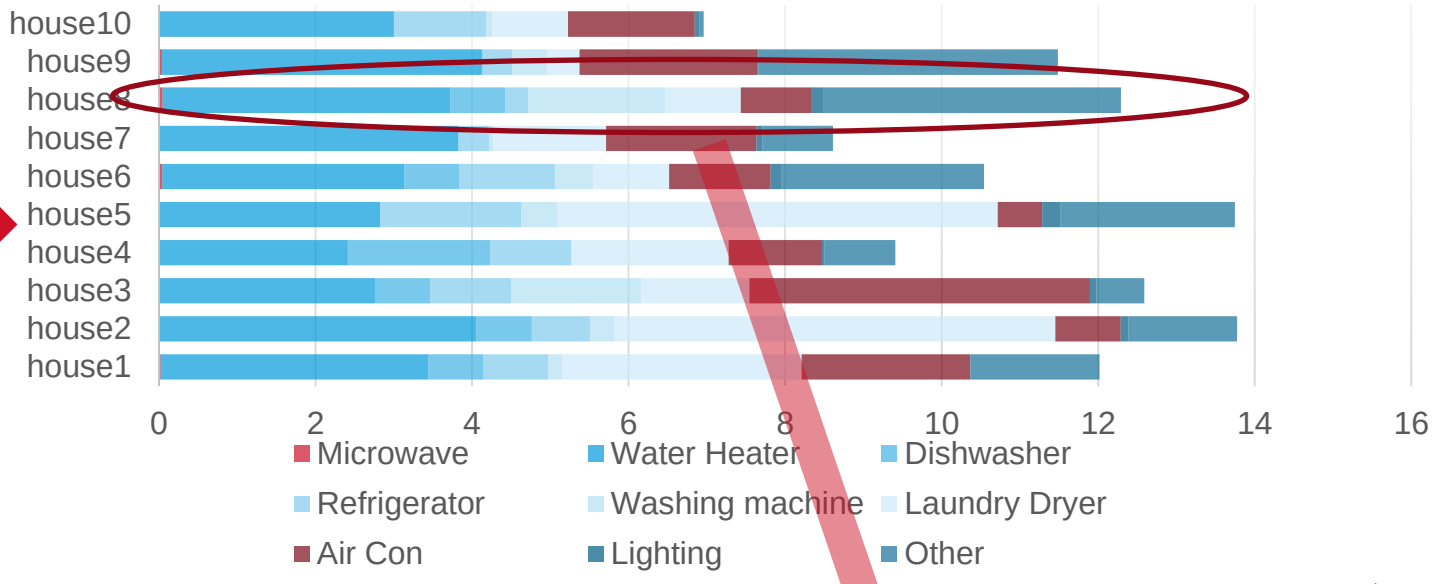
Low DR Potential

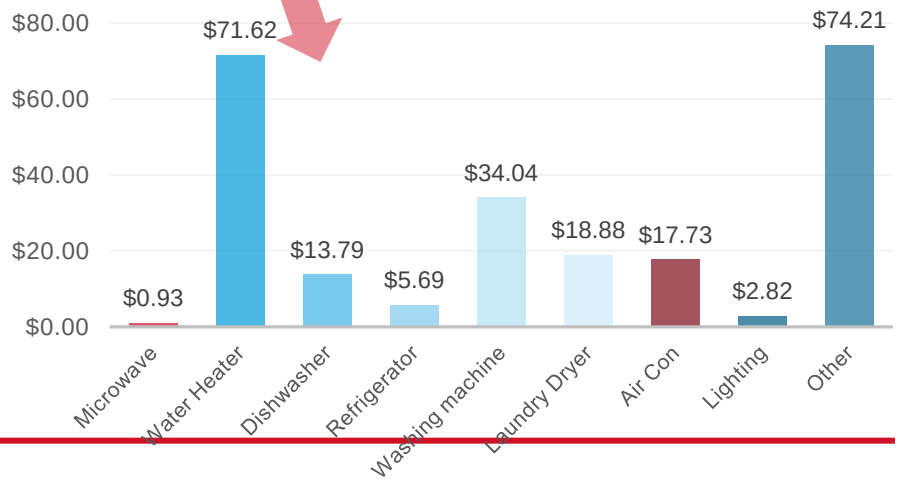
Facilitate Smart Grid Tech: Demand Response



- This is an example of what insights the NILM technology can provide
- After disaggregating, we found that house3 consumes the most for air-con. Therefore, house3 may be of the greatest interest for **monetary based demand reduction** program
- Also, we may look deeper into the minute-to-minute consumption profile of each appliance to learn the time when this user is most likely to participate in demand reduction.

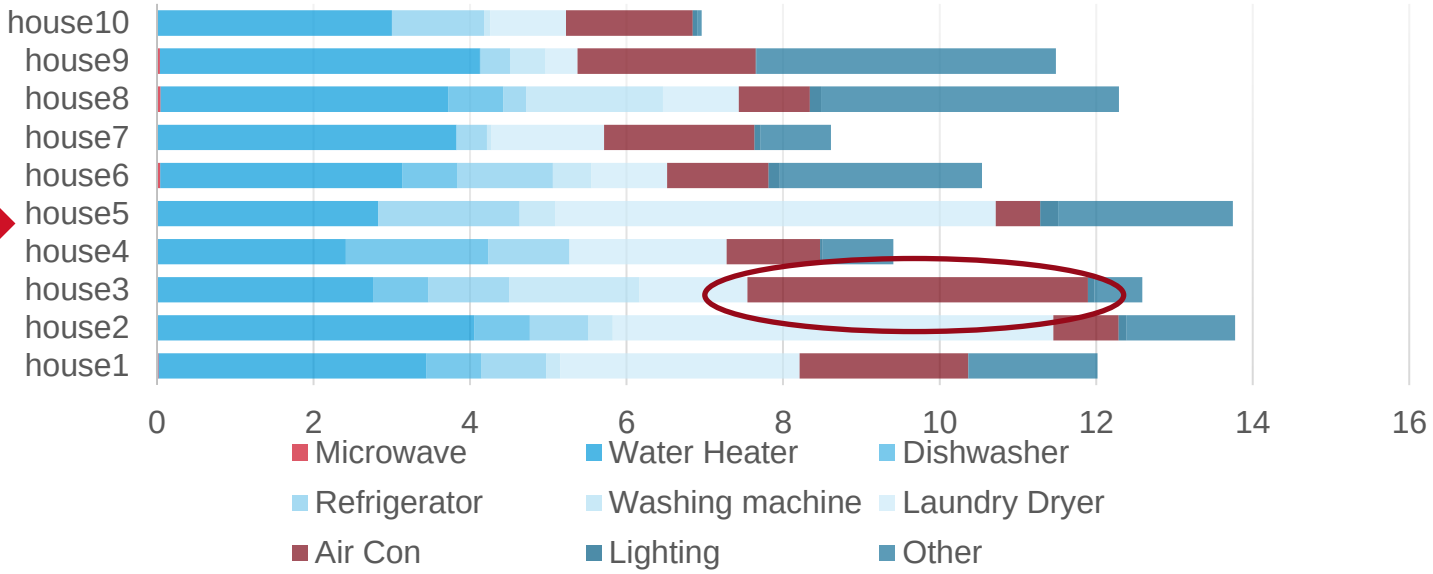
Facilitate Smart Grid Tech: Energy Awareness





- With NILM technology, the electricity bill of an household can be itemized
- This information cultivates better energy awareness for customers

Facilitate Smart Grid Tech: Energy Awareness

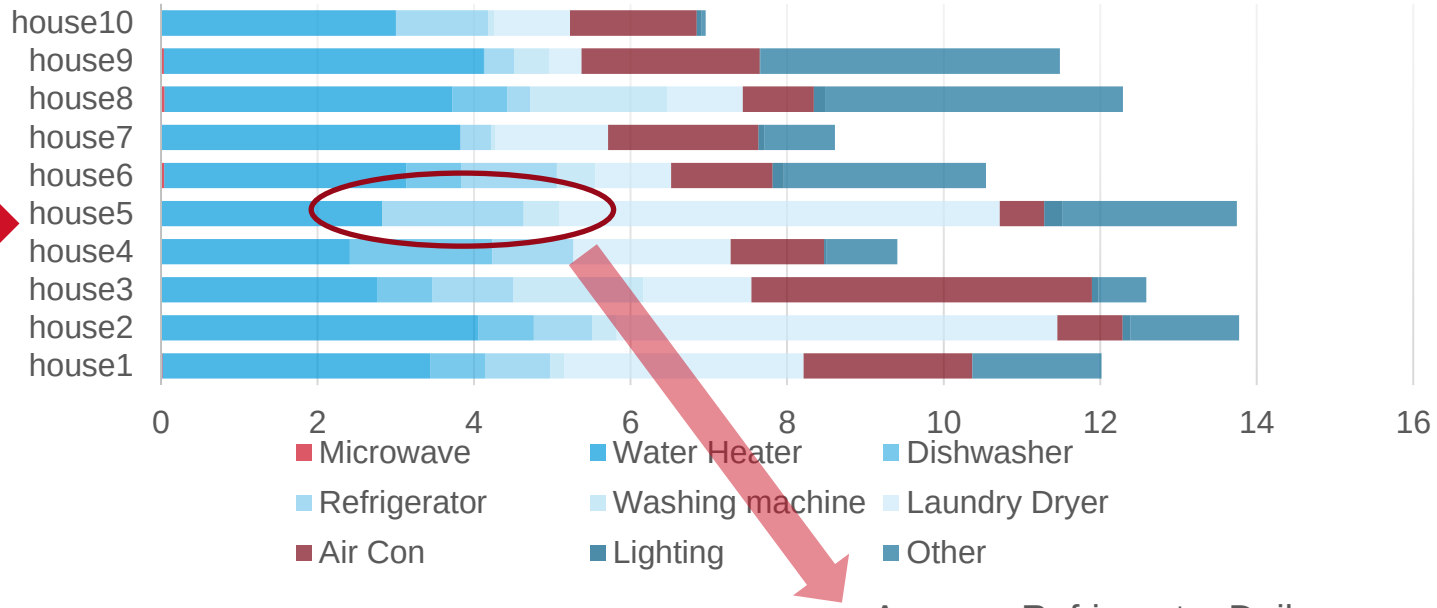


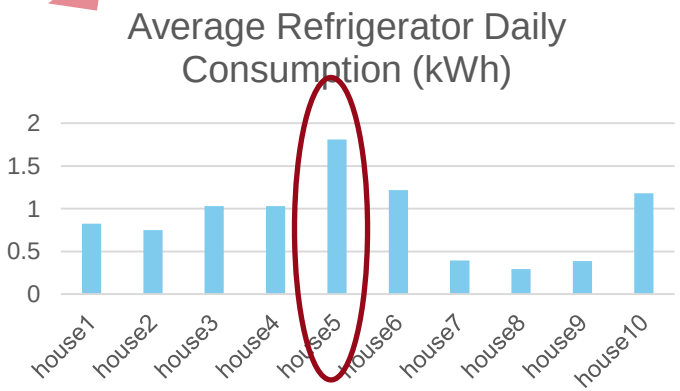
- by disclosing the comparison of the NILM results between the customers, it will trigger the behavioral reaction leading to save more energy and lower the electricity bills[2]

- In this example, house3 can realize that they are using much higher electricity in air-con than social average. This may make the householders to double check whether their high usage is necessary and remember to switch off the air-con when no one is in the room

[2]https://opower.com/

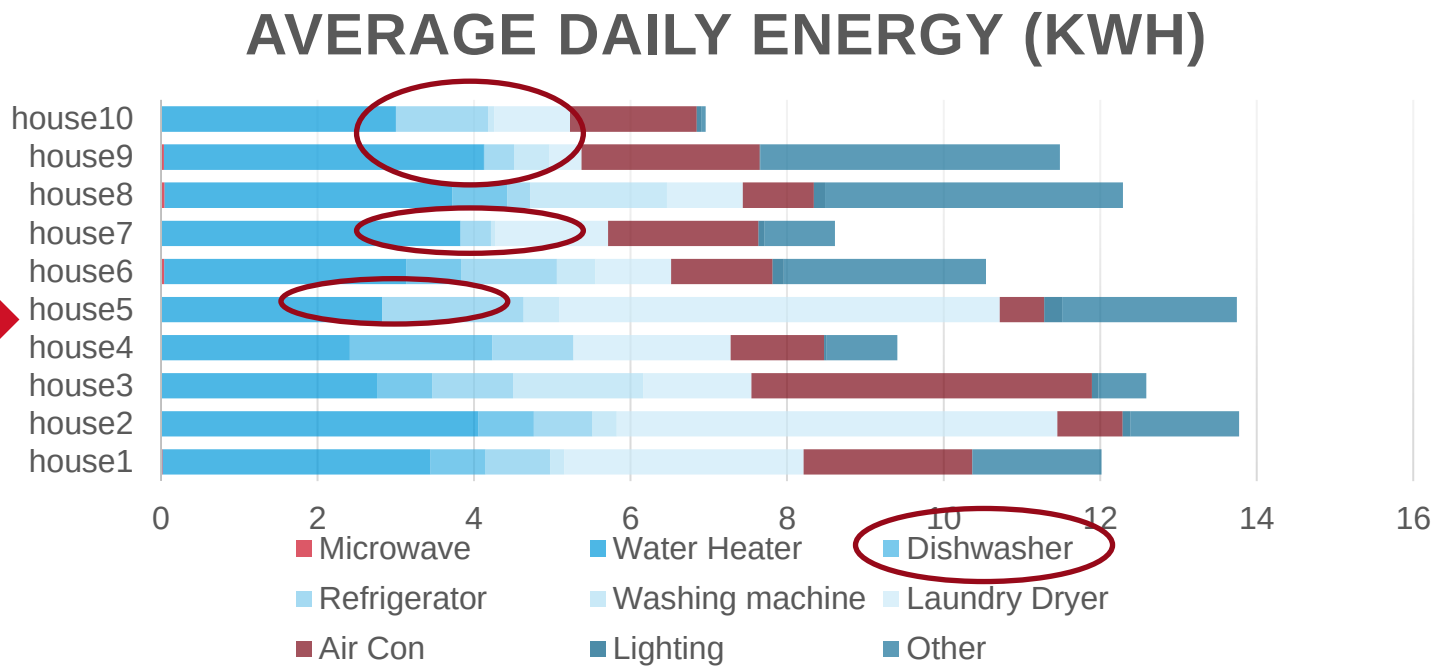
Facilitate Smart Grid Tech: Advertisement





- As this example, NILM may help us to spot that house 5 consume much higher energy than social average for refrigerator
- This could mean that either this household uses an **aged model or a low efficient model**
- So we can target this house to recommend more efficient models of fridge or alert the user to inspect the fridge

Facilitate Smart Grid Tech: Advertisement

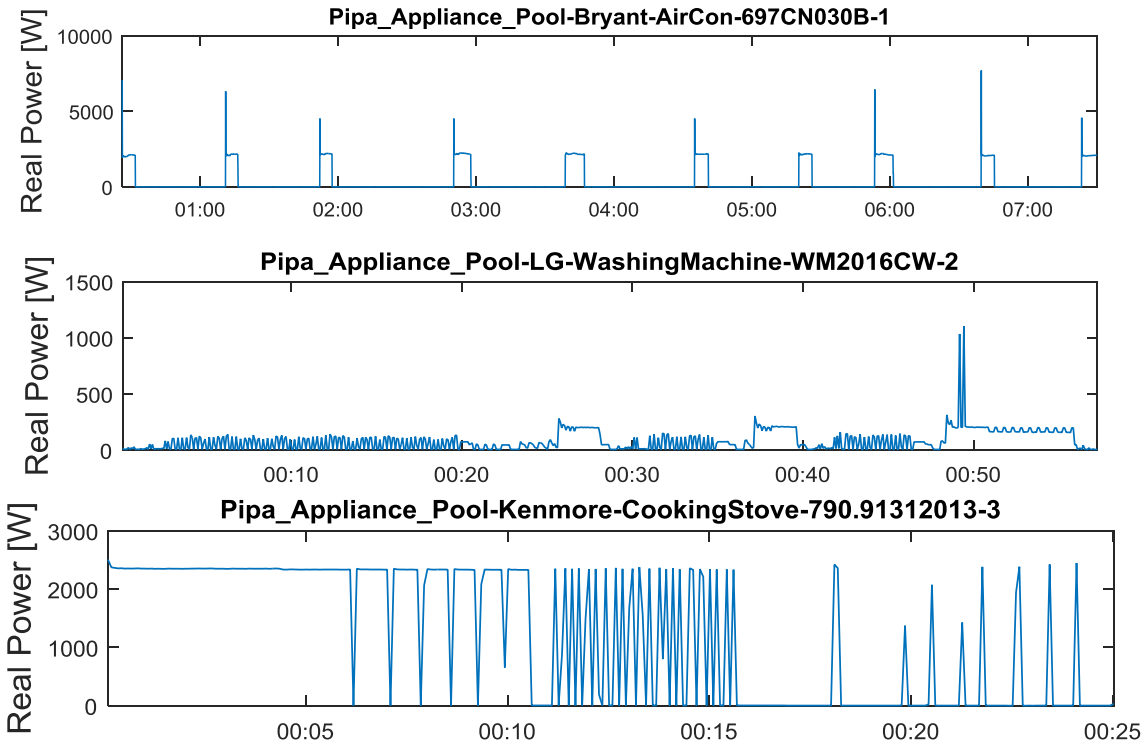


- On the other hand, house5, 7, 9 and 10 are found that they are equipped with dishwasher. Using dishwasher is a much more economical and efficient way to wash cooking utensils and plates

- So these customers can be targeted for dishwasher recommendations.

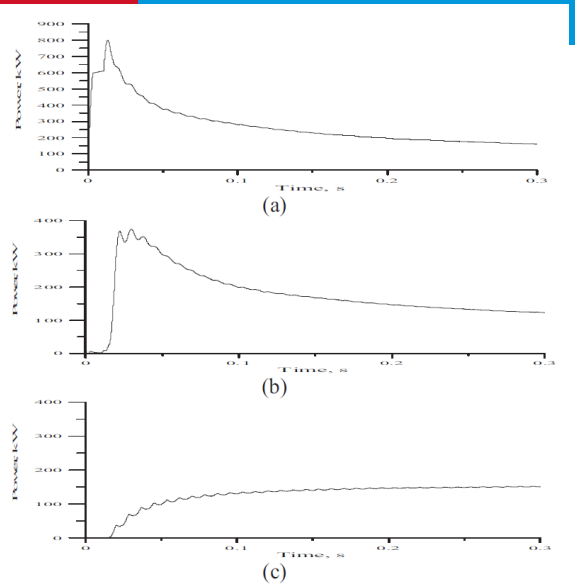
Power Signature

Each type of electric appliances has a unique fingerprint, it is also called the *Power Signature.*

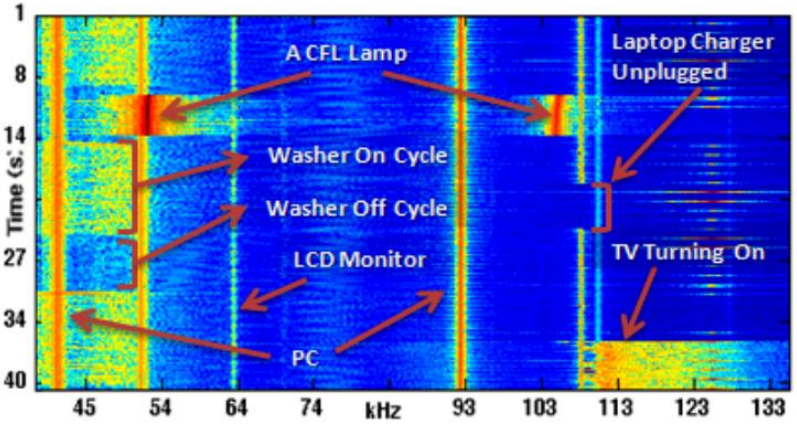


[4]M. Pipattanasomporn et al, "Load Profiles of Selected Major Household Appliances and Their Demand Response Opportunities," Smart Grid, IEEE Trans on, vol. 5, pp. 742-750, 2014

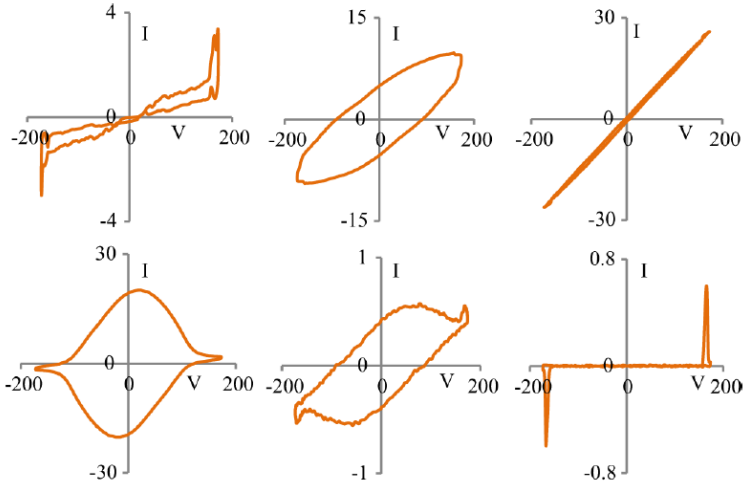
Power Signatures



Startup transient[4]



Harmonics[5]



V-I trajectories[6]

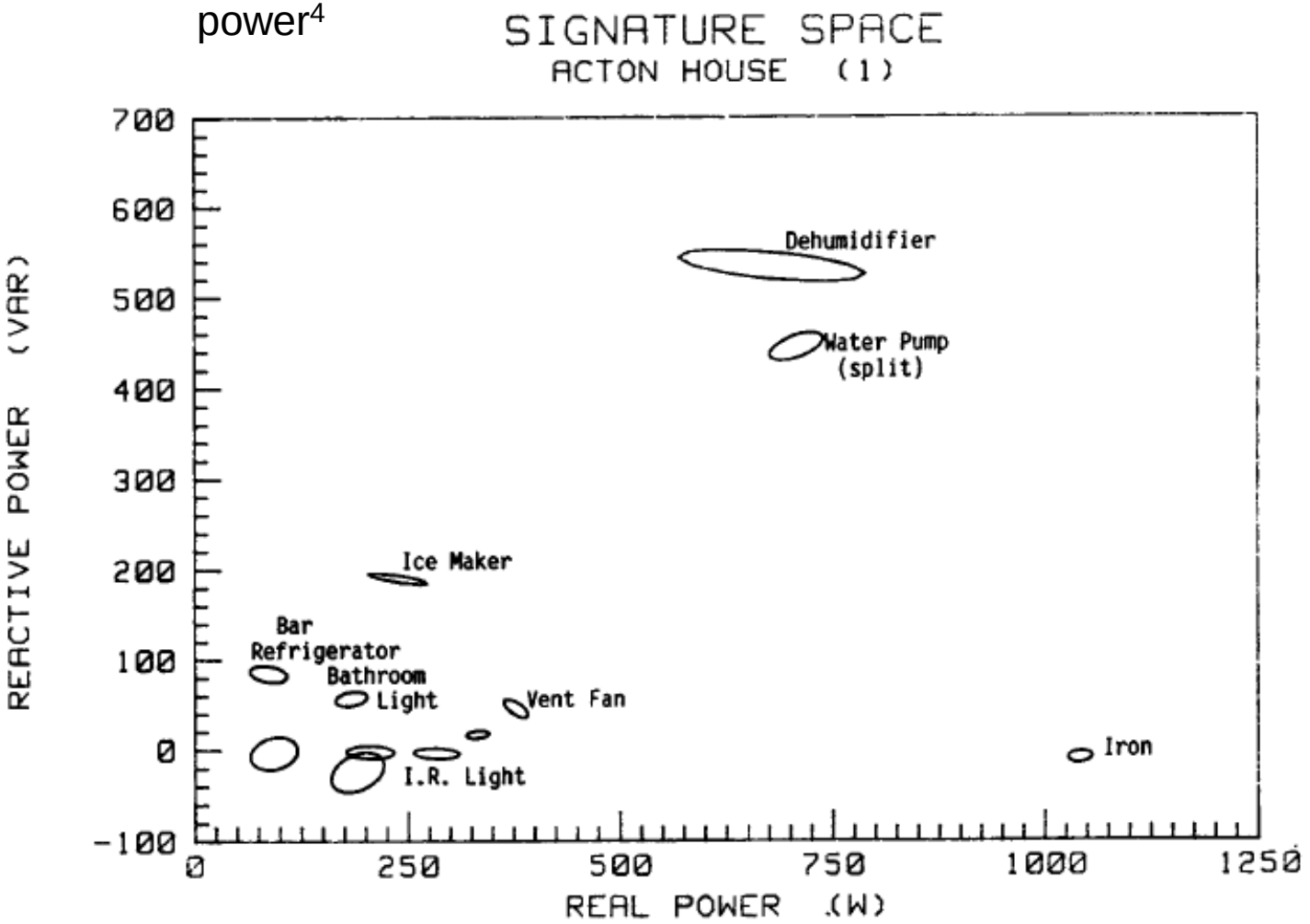
[5]C. Hsueh-Hsien, L. Ching-Lung, and J.-K. Lee, "Load identification in nonintrusive load monitoring using steady-state and turn-on transient energy algorithms," in *Computer Supported Cooperative Work in Design (CSCWD), 2010 14th International Conference on*, 2010, pp. 27-32.

[6]S. Gupta, M. S. Reynolds, and S. N. Patel, "ElectriSense: single-point sensing using EMI for electrical event detection and classification in the home," presented at the Proceedings of the 12th ACM international conference on Ubiquitous computing, Copenhagen, Denmark, 2010.

[7]T. Hassan, F. Javed, and N. Arshad, "An Empirical Investigation of V-I Trajectory Based Load Signatures for Non-Intrusive Load Monitoring," *Smart Grid, IEEE Transactions on,* vol. 5, pp. 870-878, 2014

Power Signatures

The classic power signature: real power and reactive power[4]



[4]G. W. Hart, "Nonintrusive appliance load monitoring," *Proceedings of the IEEE,* vol. 80, pp. 1870-1891, 1992.

Limitations of the above power signatures

- These features are not available with current smart meter infrastructure
- They normally rely on high sampling frequency measuring instrument
- For example, it is reported the sampling rate should be at least 8000Hz in order to utilise electric harmonics for appliance power signatures[8]
- High sampling rates will generate huge amount of data, which impose challenges on efficient storing and transmitting data over network

[8]NSMP, "Smart Metering Infrastructure Minimum Functionality Specification," 2011.

Energy Internet – Market Potential example

Bureau of Energy and Resources, China :

- Energy Internet Alliance
- Based on Industrial 4.0 to push up efficiency
- **Energy Internet opens up a $1 trillion market**
- Business opportunities:
  - power dispatch, energy exchange market, microgrid, energy product trading, energy resource asset management services, energy value added services, e-commerce services, … …

http://wallstreetcn.com/node/216954

Challenges and Opportunities

- Power system is no longer a single system, it interacts with other systems such as ICT, primary energy, transportation etc.
- Systems of system approach leads to Energy Internet
- Renewable energy can potentially serve base energy needs supported by a strong network
- Efficiency energy market is required to form appropriate economic stimulation for future energy networks
- Energy storage, big data analytics, internet of things and next generation telecommunications are key technological enabling techniques

Thank you

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