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at

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Overview

- Introduction

- Microgrids
  - Planning: Lifelines, renewable energy sources and energy storage availability modeling
  - Circuits: Multiple-input dc-dc converters and power routing interfaces
  - Control: constant power loads and maximum power point tracking

- Smart Grids
  - Pecan Street “customer side of the meter”

- Data centers and other relevant topics

Introduction

- Top to Bottom Research Approach

- Power electronics research often refers to:
  - circuits
  - controls
  - devices

- But significant issues appears when integrating all components into systems. Analysis from a system approach tends to be uncommon in traditional power electronics research.

- Some key focus topics from a system approach includes modeling, availability, energy efficiency, operational flexibility.

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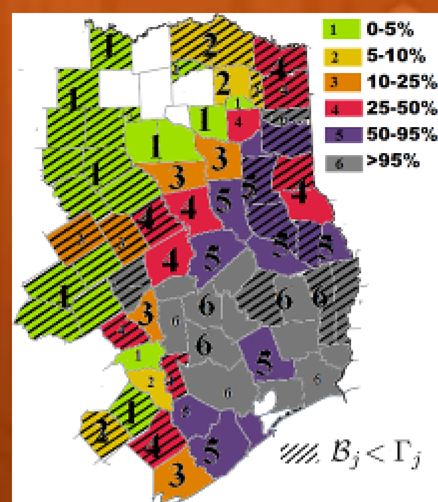
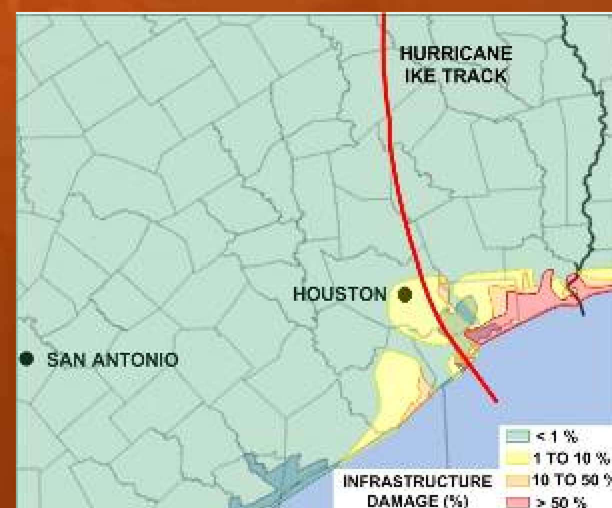
Problem Formulation

- Conventional power grids are very fragile systems

- Work underway in modeling hurricane intensity as a function of their effect on conventional power grids

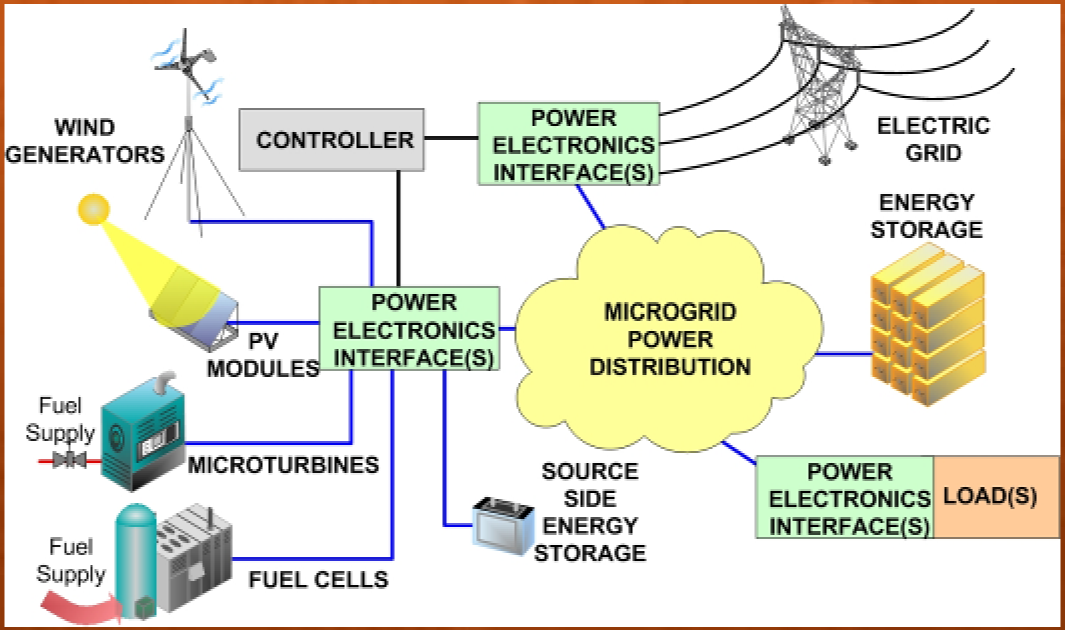




Microgrids

• What is a microgrid?

• Microgrids are considered to be locally confined and independently controlled electric power grids in which a distribution architecture integrates loads and distributed energy resources—i.e. local distributed generators and energy storage devices—which allows the microgrid to operate connected or isolated to a main grid



Microgrids

- Highly available power supply during disasters

•Power electronic enabled micro-grids may be the solution that achieves reliable power during disasters (e.g. NTT's micro-grid in Sendai, Japan)

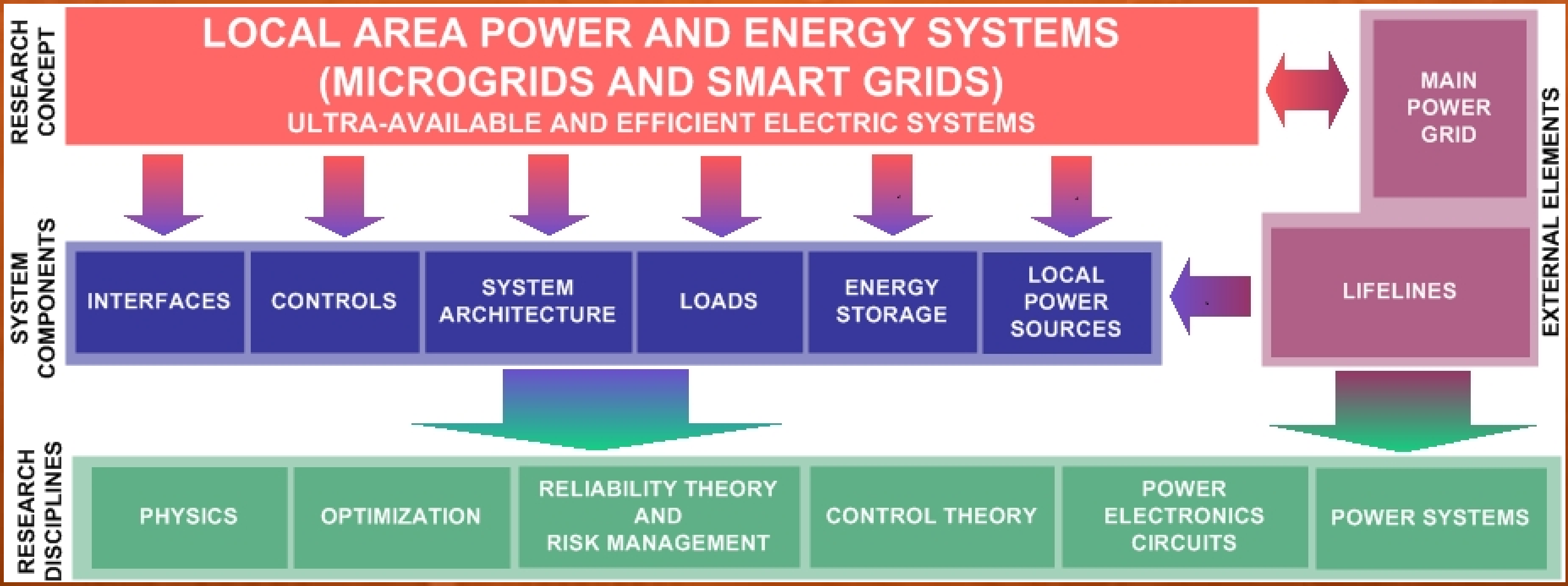
Microgrids

- Highly available power supply during disasters

- Focus on critical loads, such as communications facilities.
- E.g. Verizon's Garden City Central Office after Irene.

Power Electronics Research

- Research view for power electronics systems

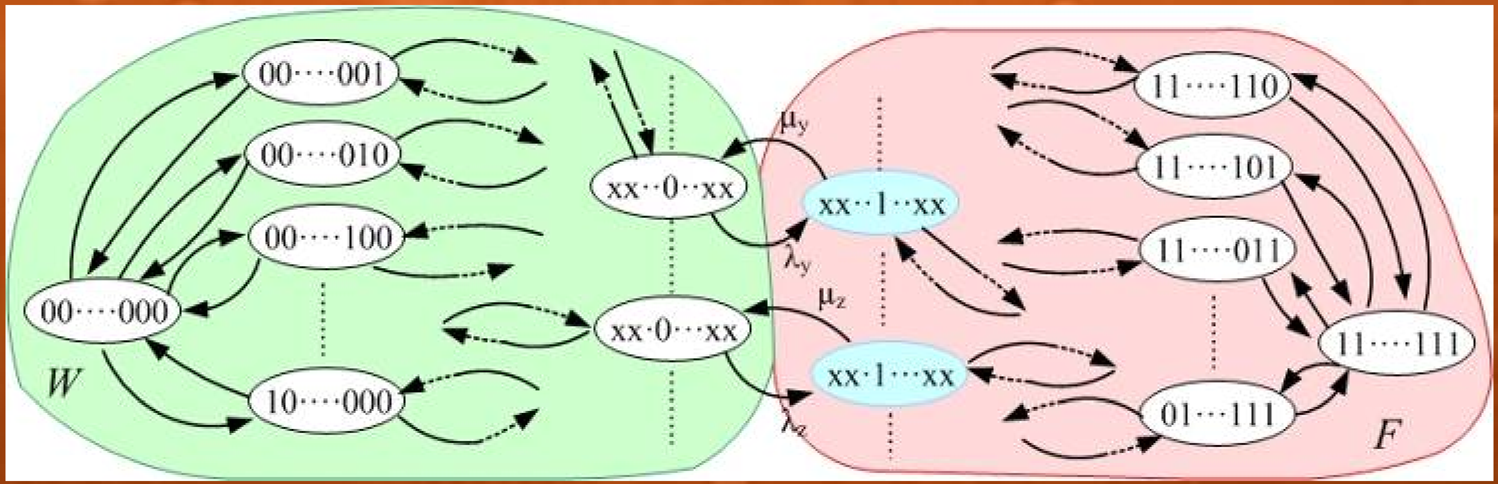


- Selected applications:
  - power during natural disasters
  - electric ship
  - microgrids

Microgrids Availability

- Calculation using minimal cut sets

- A minimal cut set is a group of components such that if all fail the system also fails but if any one of them is repaired then the system is no longer in a failed state. Much simpler than Markov approaches.



- Approximation with highly available components and no energy storage:

$$U_{MG} \cong \sum_{j=1}^{M_C} \mathrm{P}(K_j)$$

Micrograds

• Lifelines and energy storage

• Local generators depend on other infrastructures, called lifelines (e.g. natural gas distribution networks or roads)

• But lifelines can be affected by the natural disaster like conventional grids.

• Approaches to address lifeline dependencies:
  - Diverse power source technologies
  - Local Energy Storage: $U_{MG,T} = U_{MG} e^{-\mu_{FW} T_{BAT}}$

Microgrids

- Renewable energy sources

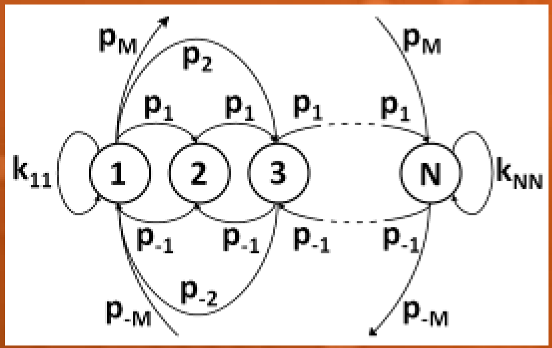
- Renewable energy sources do not need lifelines, but their output varies and they have large footprints.

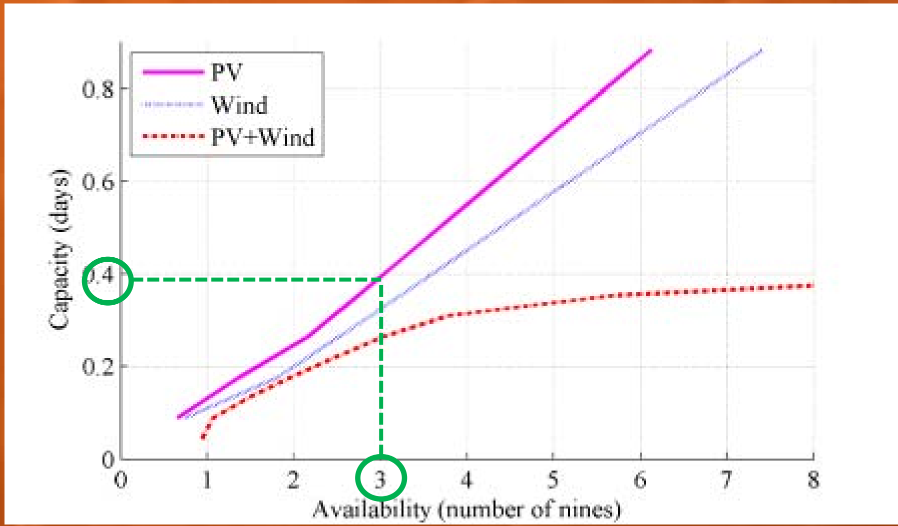
- Approaches to address variable output:
  - Diverse power source technologies (combine PV and wind)
  - Add energy storage

Microgrids

• Renewable energy sources

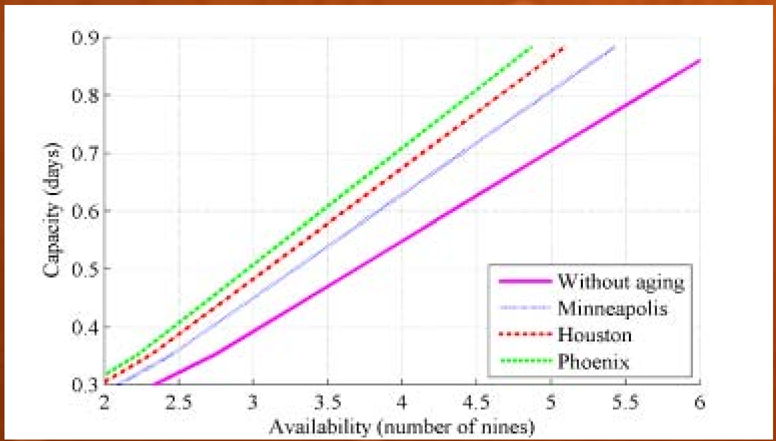
• Markov based availability modeling of renewable energy sources considering energy storage





6 MW PV + 1.5 MW Wind – 700 Housing Load (944 kW)

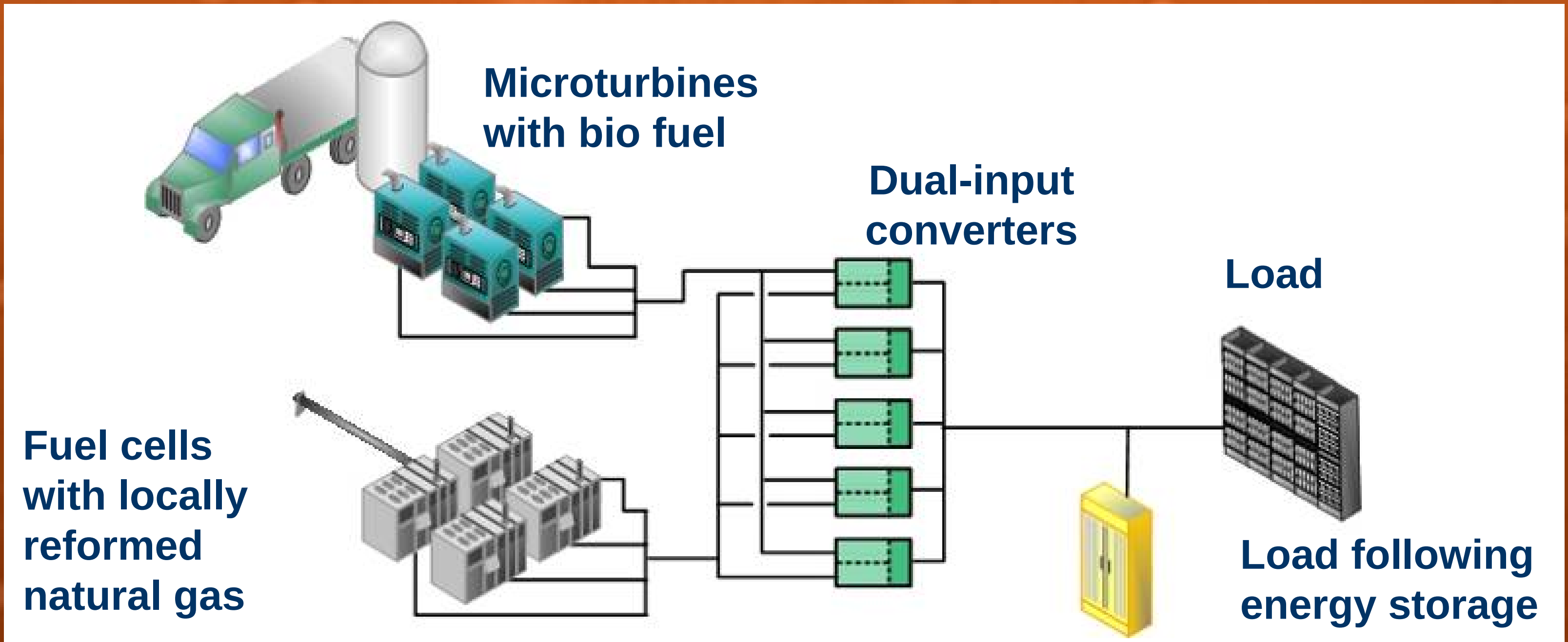
(Example) 0.4 days × 24 hours × 944 kW = 9.06 MWh



• The model can predict effects of temperature, dust, and other practical issues

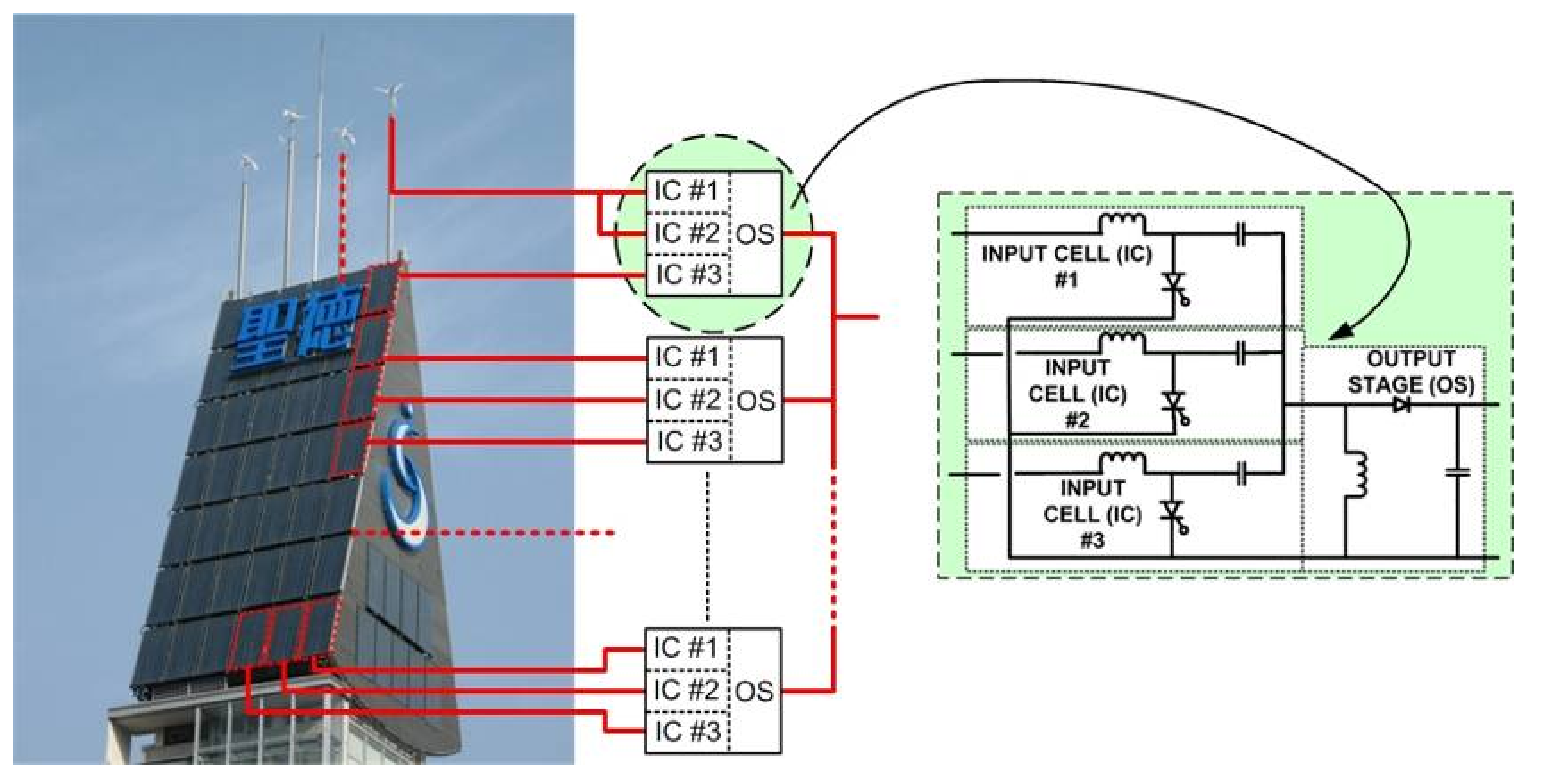
Multiple-input converters

- Cost effective solution for integrating diverse power sources without compromising reliability or efficiency.
- Effective way for integrating power sources with inherently low output voltage (e.g. fuel cells, PV cells, batteries) by reducing the number of series connected cells.



Multiple-input converters

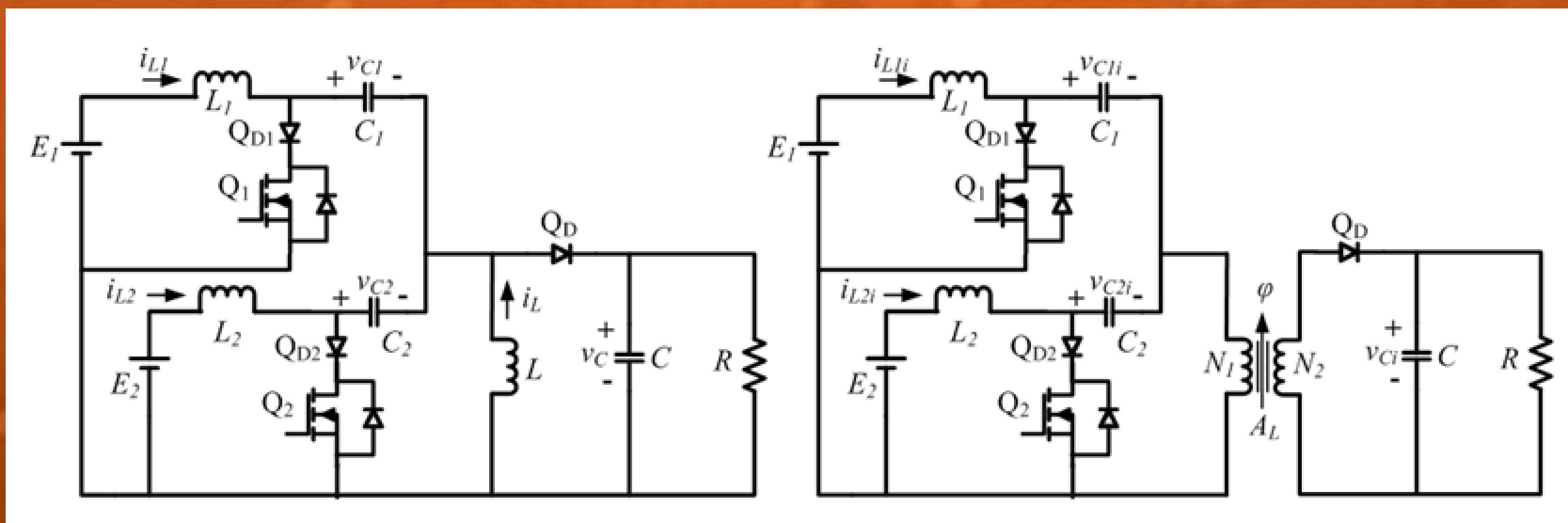
- Modular approach.
- Both voltage-source and current-source input modules (suitable for fuel cells or PV modules) have been developed.



Microgrids

- Multiple-input converters.

- Example: Isolated and non-isolated multiple-input SEPIC

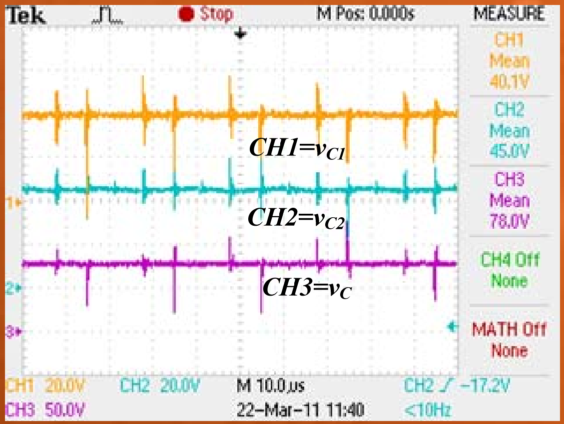


$$V_{out,i} = \frac{N_2(D_{1,i}E_1 + D_{2,i}E_2)}{N_1(1 - D_{1,i} - D_{2,i})}$$

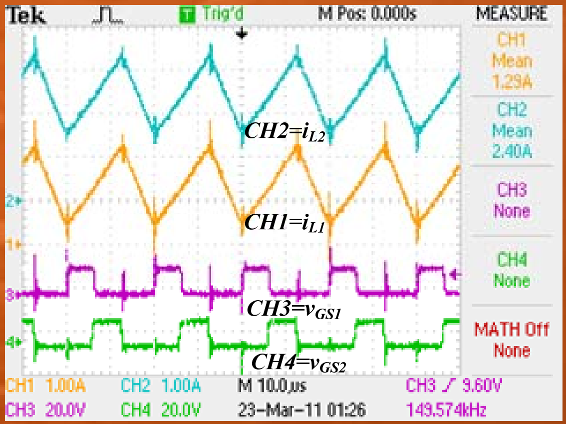
Microgrids

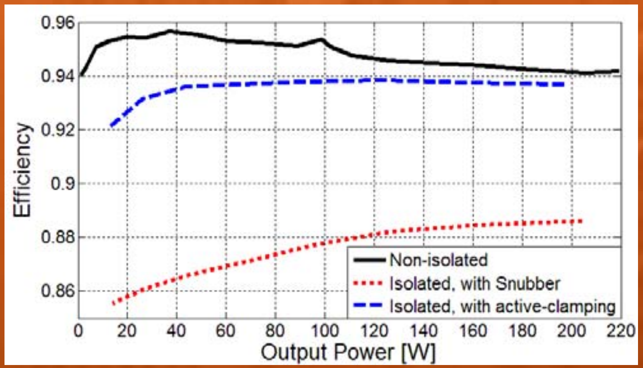
- Multiple-input converters.

Non Isolated CCM



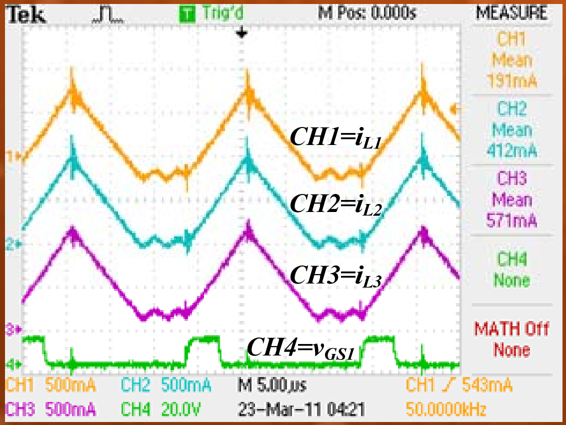
Non Isolated CCM



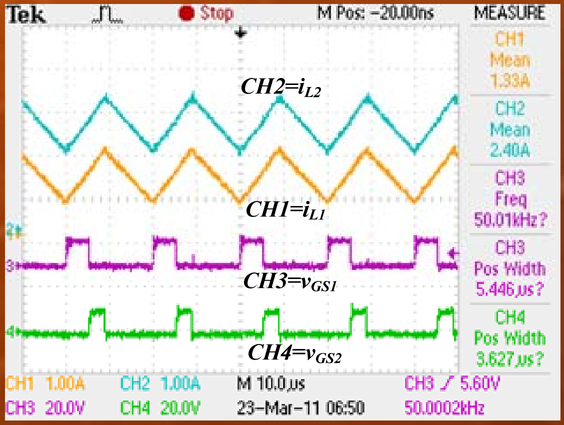


Efficiency

Non Isolated DCM

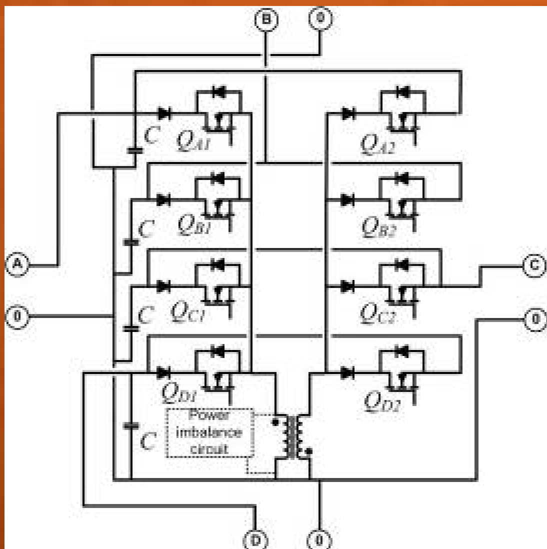


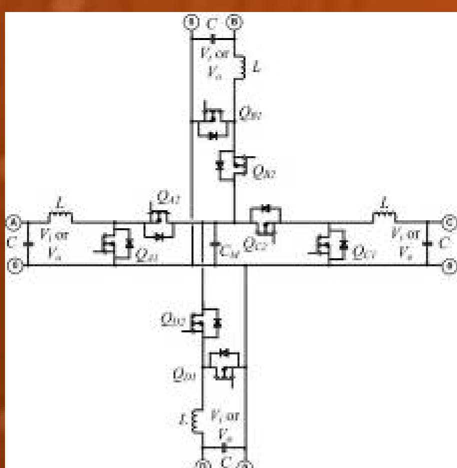
Isolated CCM

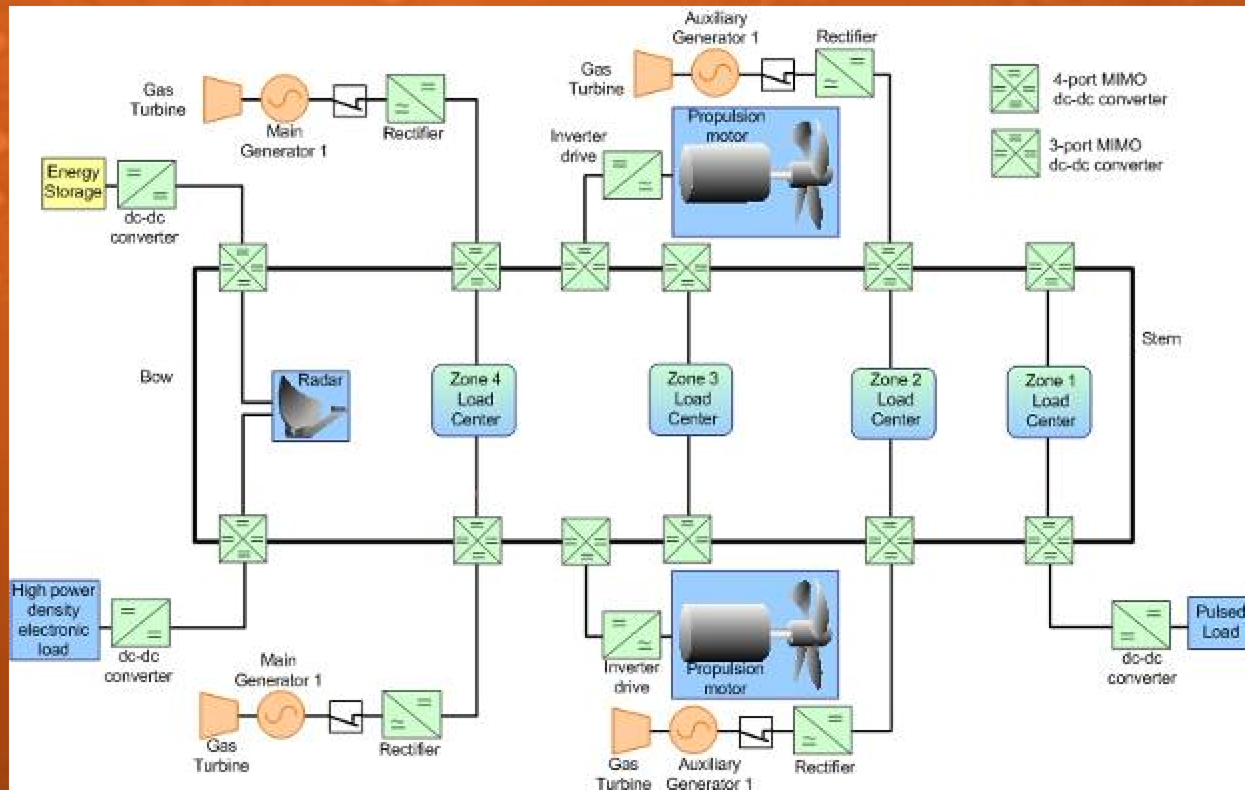


Microgrids

- Power routers (MIMO converters): application of MICs in distribution systems







- Example of application in a possible power architecture for the Navy’s electric ship.

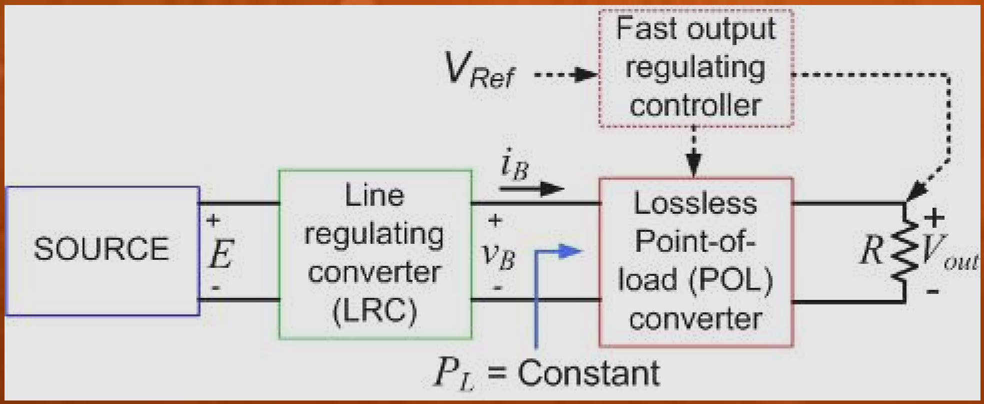
Microgrids

- Control: Constant-Power loads

- dc power architectures is a natural choice for microgrids integrating various sources, energy storage and modern loads.

- dc microgrids comprise cascade distributed architectures – converters act as interfaces

- Point-of-load converters present constant-power-load (CPL) characteristics



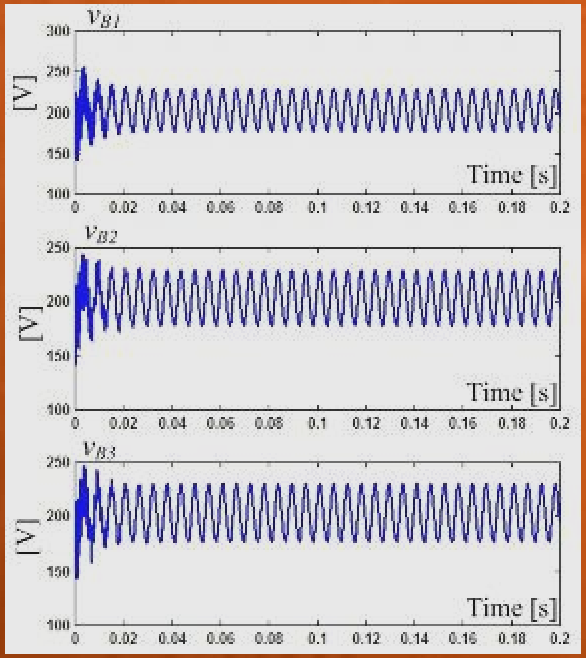
$$i(t) = \begin{cases} 0 & \text{if } v(t) < V_{\lim} \\ \dfrac{P_L}{v(t)} & \text{if } v(t) > V_{\lim} \end{cases}$$

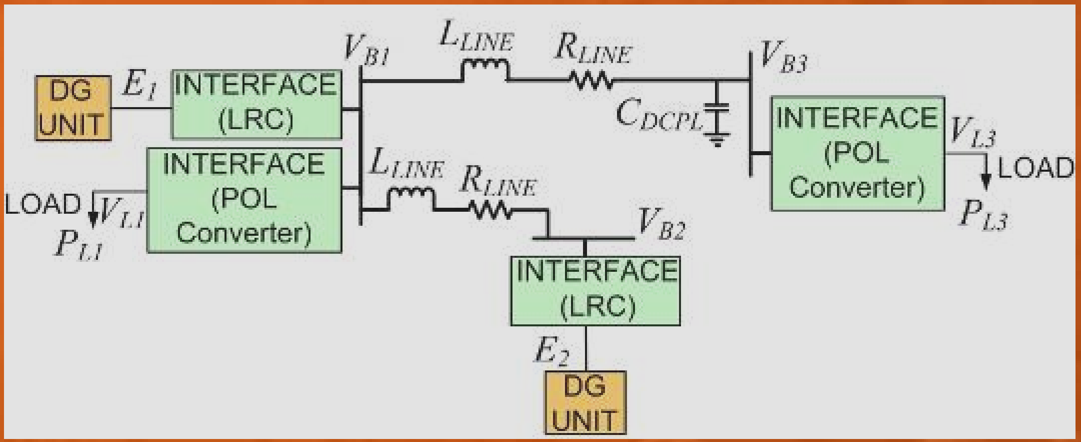
$$\delta z = \frac{dv_B}{di_B} = -\frac{P_L}{i_B^2}$$

- CPLs introduce a destabilizing effect in dc microgrids

Microgrids

- Control: Constant-Power loads



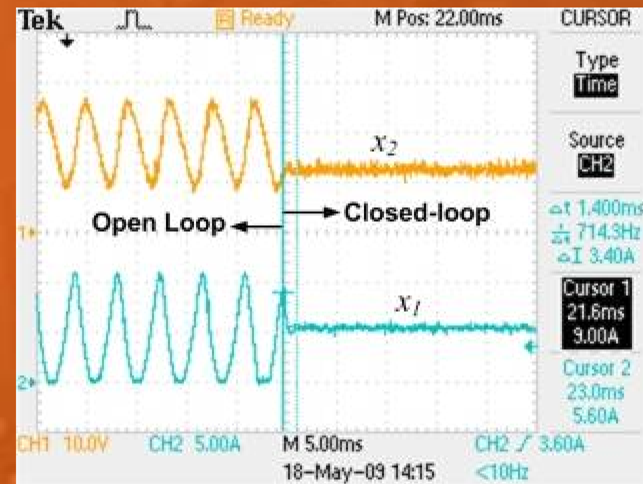


$$E_1 = 400V, E_2 = 450V, P_{L1} = 5kW, P_{L2} = 10kW,$$
$$L_{LINE} = 5\mu H, R_{LINE} = 10m\Omega, C_{DCPL} = 1mF$$
$$L = 0.5mH, C = 1mF, D_1 = 0.5, D_2 = 0.54, R_L = 0.8\Omega$$

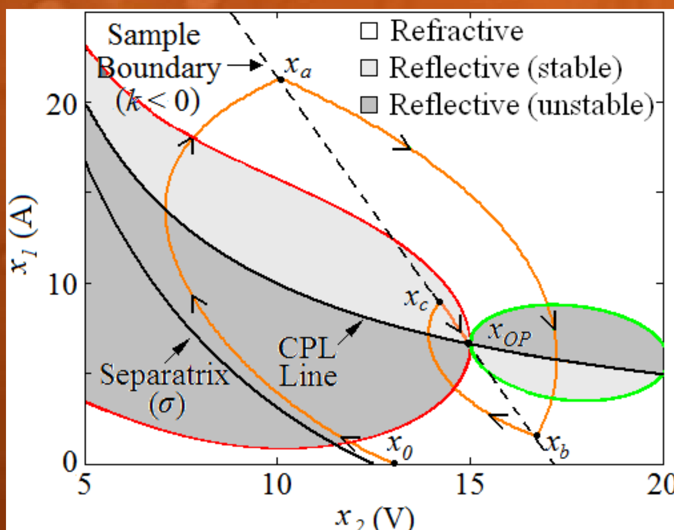
- Without proper controls large oscillations and/or voltage collapse is observed.
- We were the first ones to show why the conventional approach of using PID controllers was a valid one.

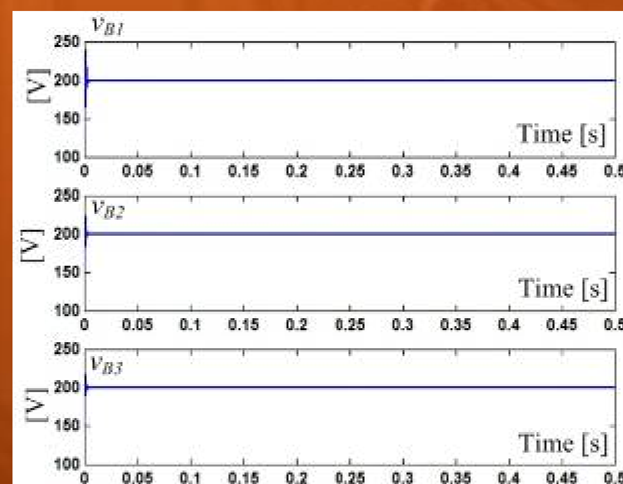
Microgrids

- Control: Constant-Power loads



- New approach: boundary control.
- Uses state-dependent switching (q = q(x))
- First-order boundary (linear switching surface with a negative slope)
- Valid for all types of converters



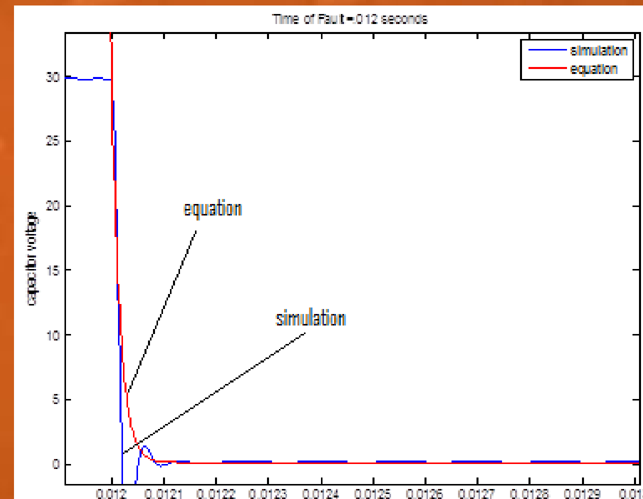


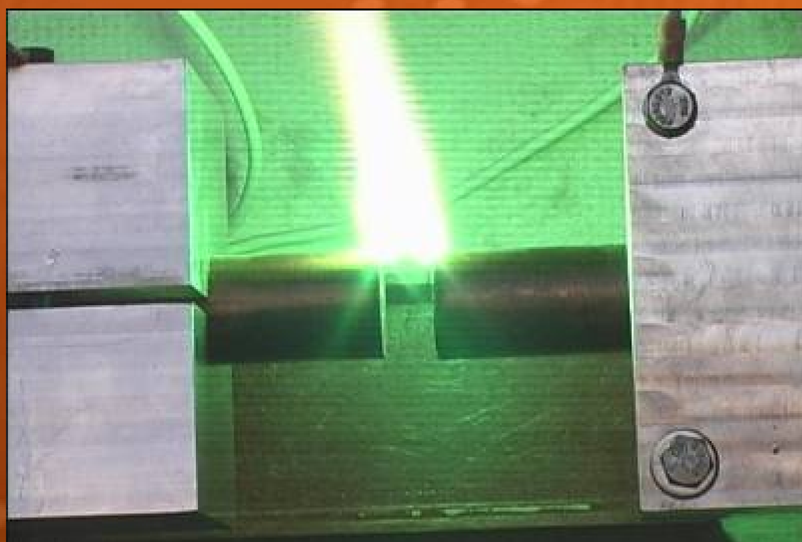
- Robust
- Very fast response
- Easy to implement

Microgrids

- Arcs and faults study

- Model developed for arcs in series faults.
- Study of parallel faults in power electronics-based systems.

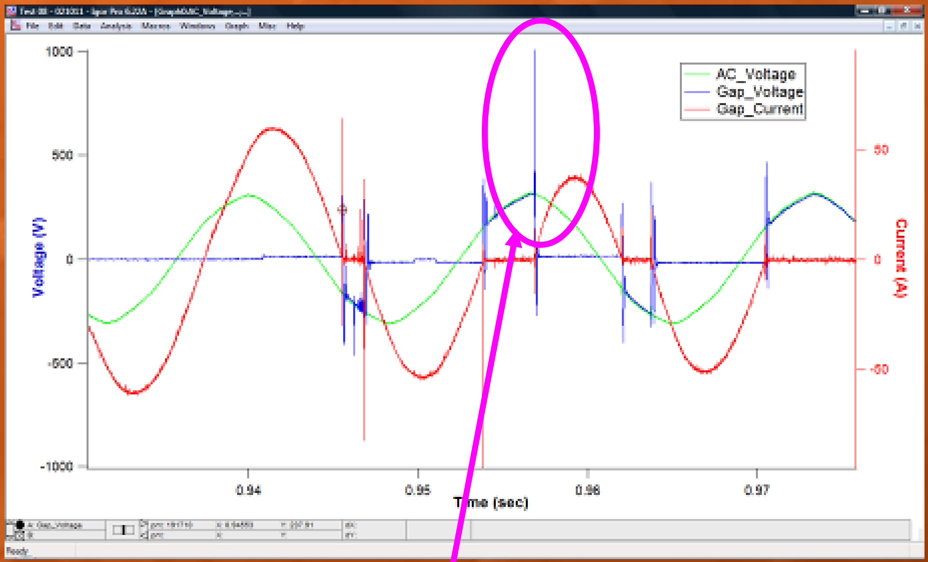




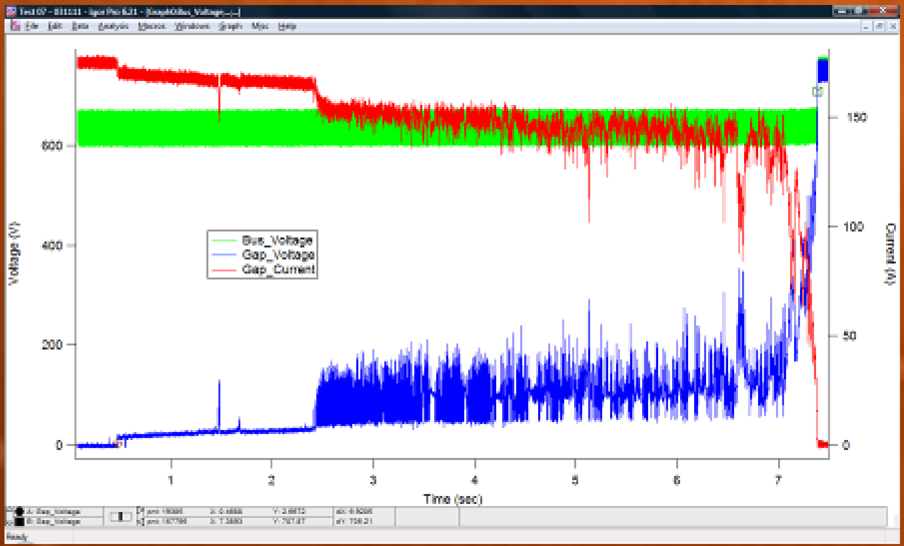
Microgrids

- Arcs and faults study

- Comparison of ac and dc systems (ac faults are electrically malign, dc faults are mechanically hazardous).



DC arcs last longer

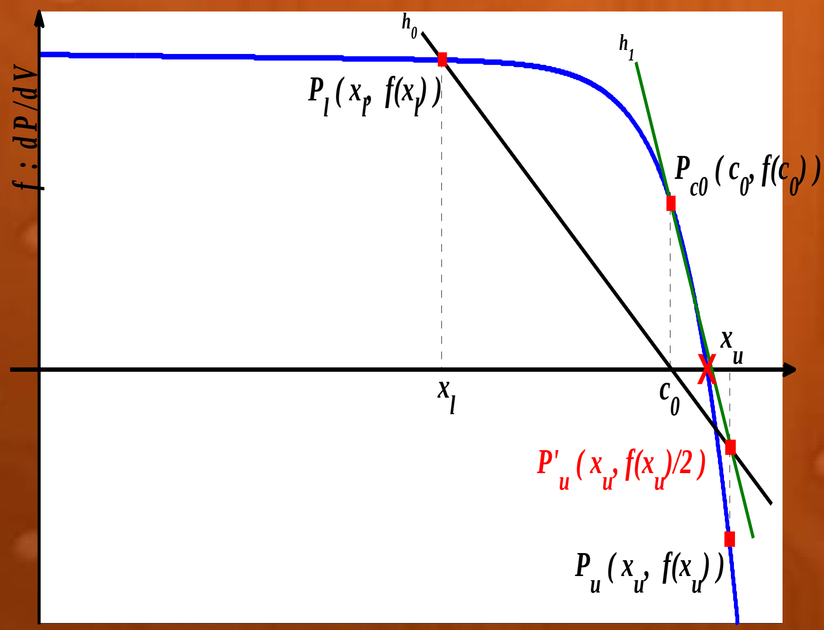


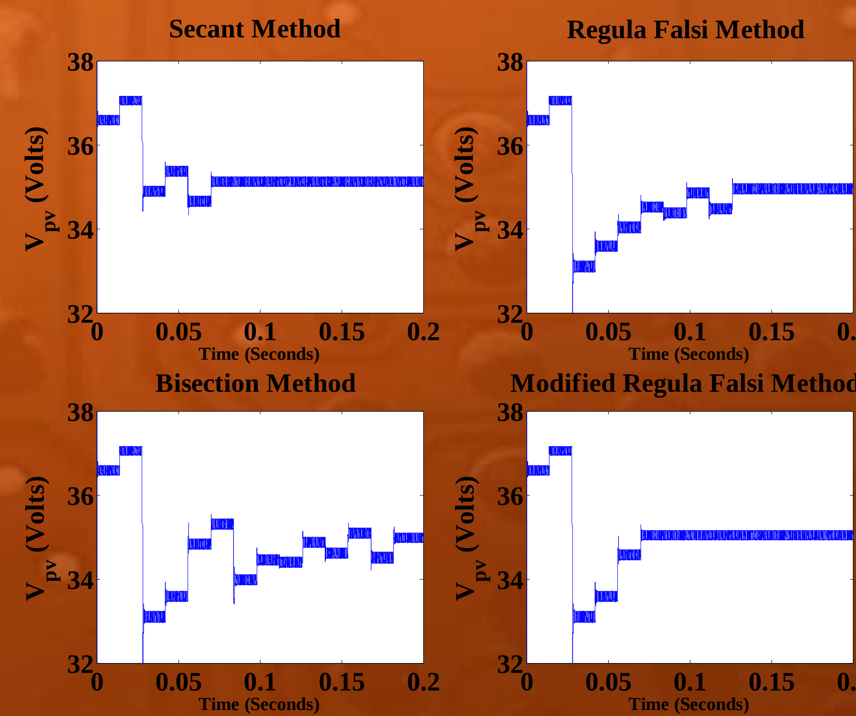
AC series faults show voltage spikes during re-strikes

Microgrids

•Control: Maximum Power Point Tracking (MPPT)

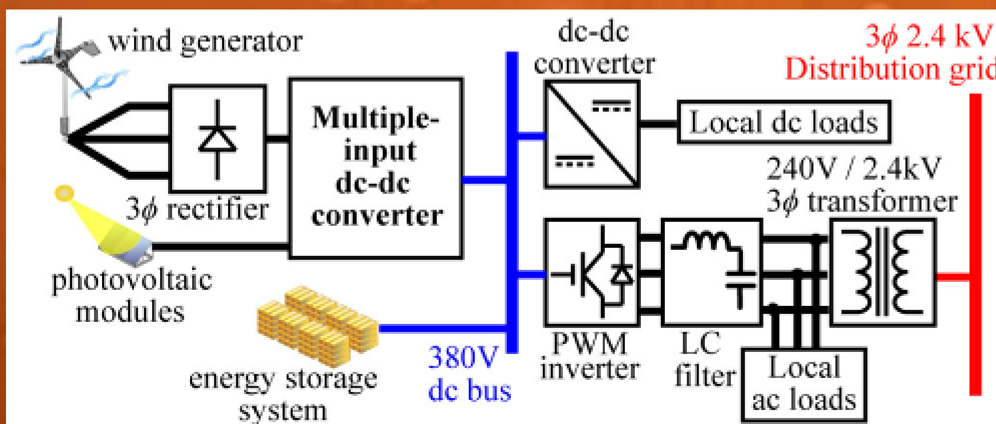
- Focus on digital implementation
- Methods based on root finding algorithms
- Developed a Modified Regula Falsi Method that ensures convergence faster than other methods

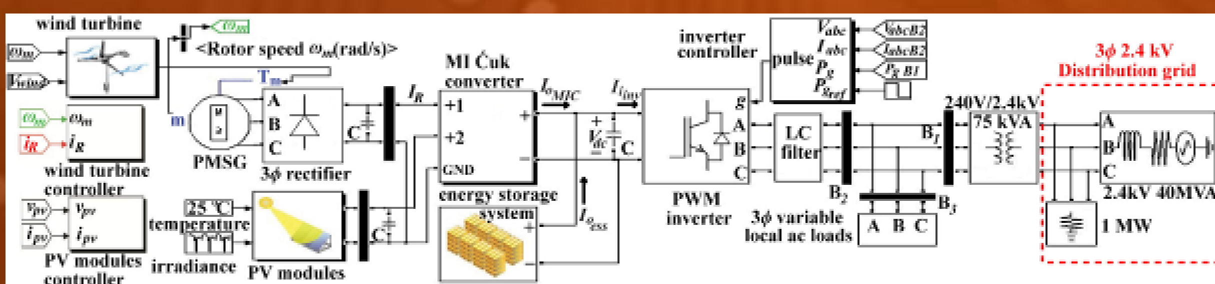


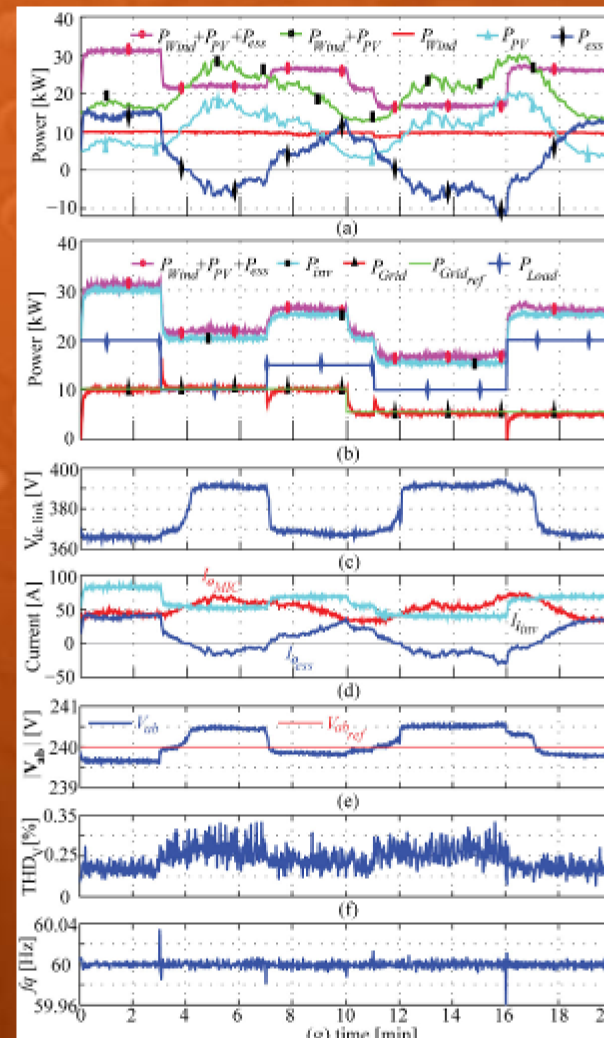


Microgrids

- Control of a self-sustained micro-grid
  - Development of a micro-grid model
  - Development of control approaches







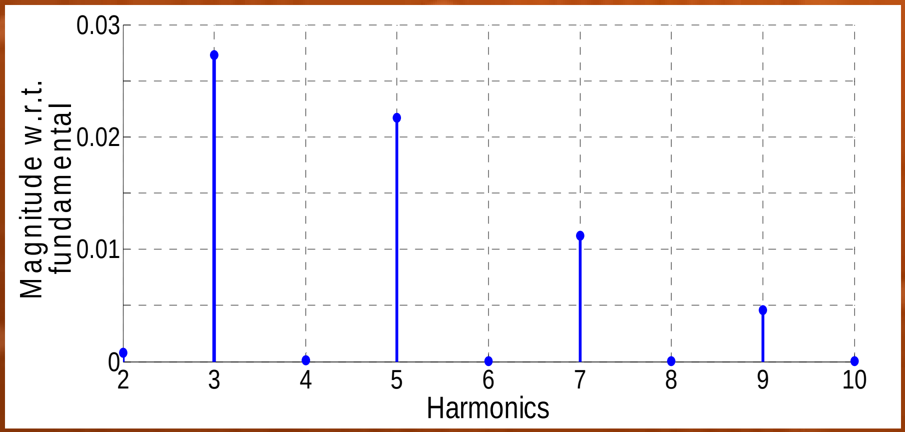
Islanding detection

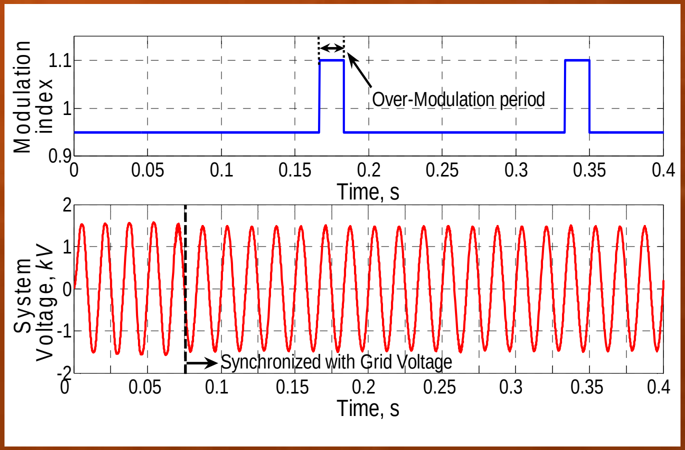
•Modulation strategy: $m_i = \begin{cases} m_{op} & 0 \le t \le 9T \\ m_{over} & 9T \le t \le 10T \end{cases}$ $m_{over} = 1.1$

• m_{over} is set to 1.1 in order to provide a good tradeoff between introducing sufficient harmonics into the system without exceeding the prescribed limit of 5% THD in IEEE Std 519-1992

• Instead of measuring the THD of the system, only one or two voltage harmonics are measured (typically the 5th and 7th)

• Advantages: smaller NDZ, no need for non-linear load, distortion injected during a short time, no synchronization issues.





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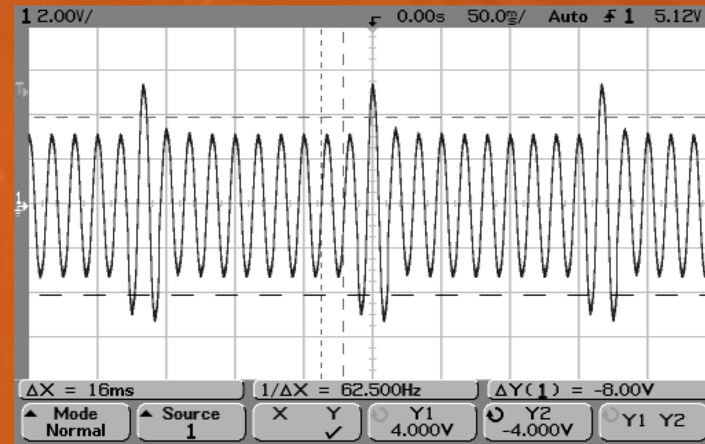
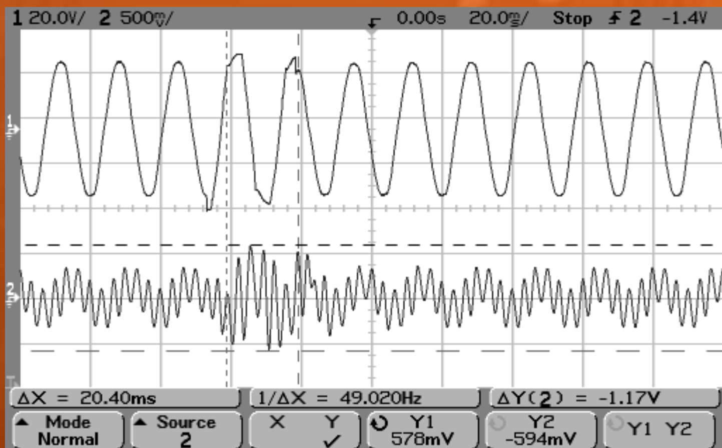
Islanding detection

- Experimental results
  - THD with the grid-connected inverter is 3.9 % (even with a very weak grid)



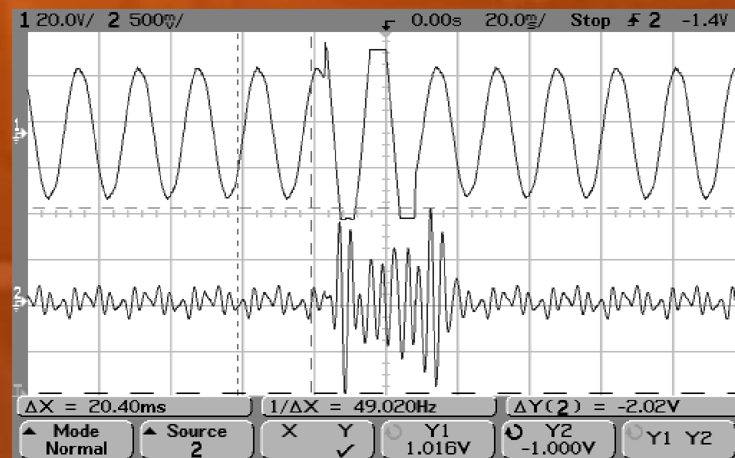
Modulation Signal



Inverter output

5th Harm.

Normal operation



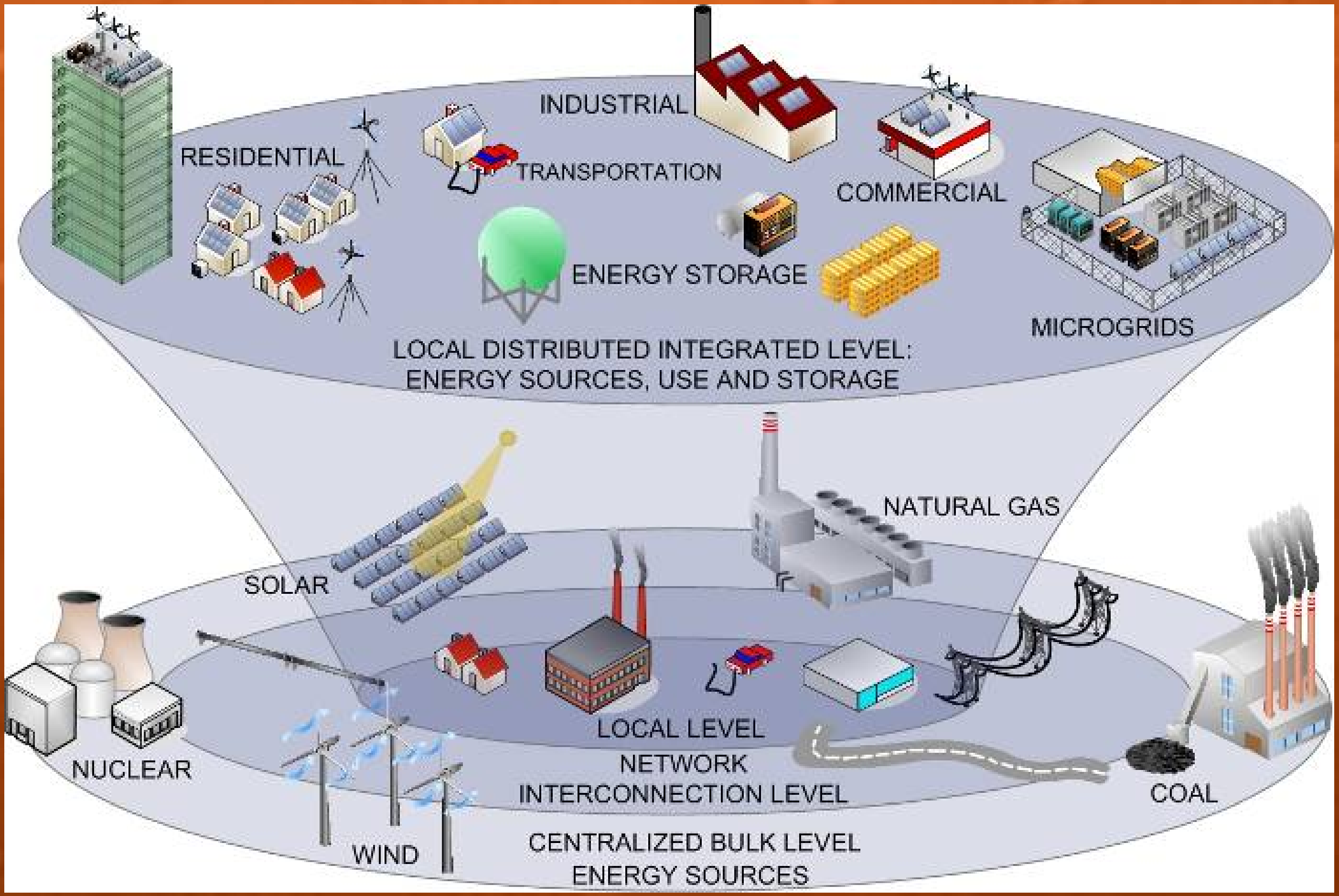
Inverter output

5th Harm.

Islanding detection

A smart grid vision

• Based at a local level, through microgrids or residential-level energy management systems



Pecan Street

- Customer focus

- Traditional grids: Generation focus

- Smart grids represent a paradigm change: now the focus in on customers

- New questions:
  - What do customers want?
  - How do they behave?
  - How do evaluate their behavior in order to obtain meaningful information? What information we need to look at?
  - How do we measure without affecting our measured parameters (smart grid version of Heisenberg uncertainty principle)?

- The paradigm change implies designing a very complex experiment.

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Pecan Street Research

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- Highlighted research areas

- Residential technologies
- Electric vehicles (EV)
- Grid's power distribution modeling.
- Data management and analysis

Residential-level Research

• Home Energy Management Systems

• Work originated in “Customer Side of the Meter” team

• Initial work providing support for testing data collection systems before being deployed.

• Next, interoperability studies, effects of different pricing models, development of energy management strategies (at home research lab), and load pattern recognition.

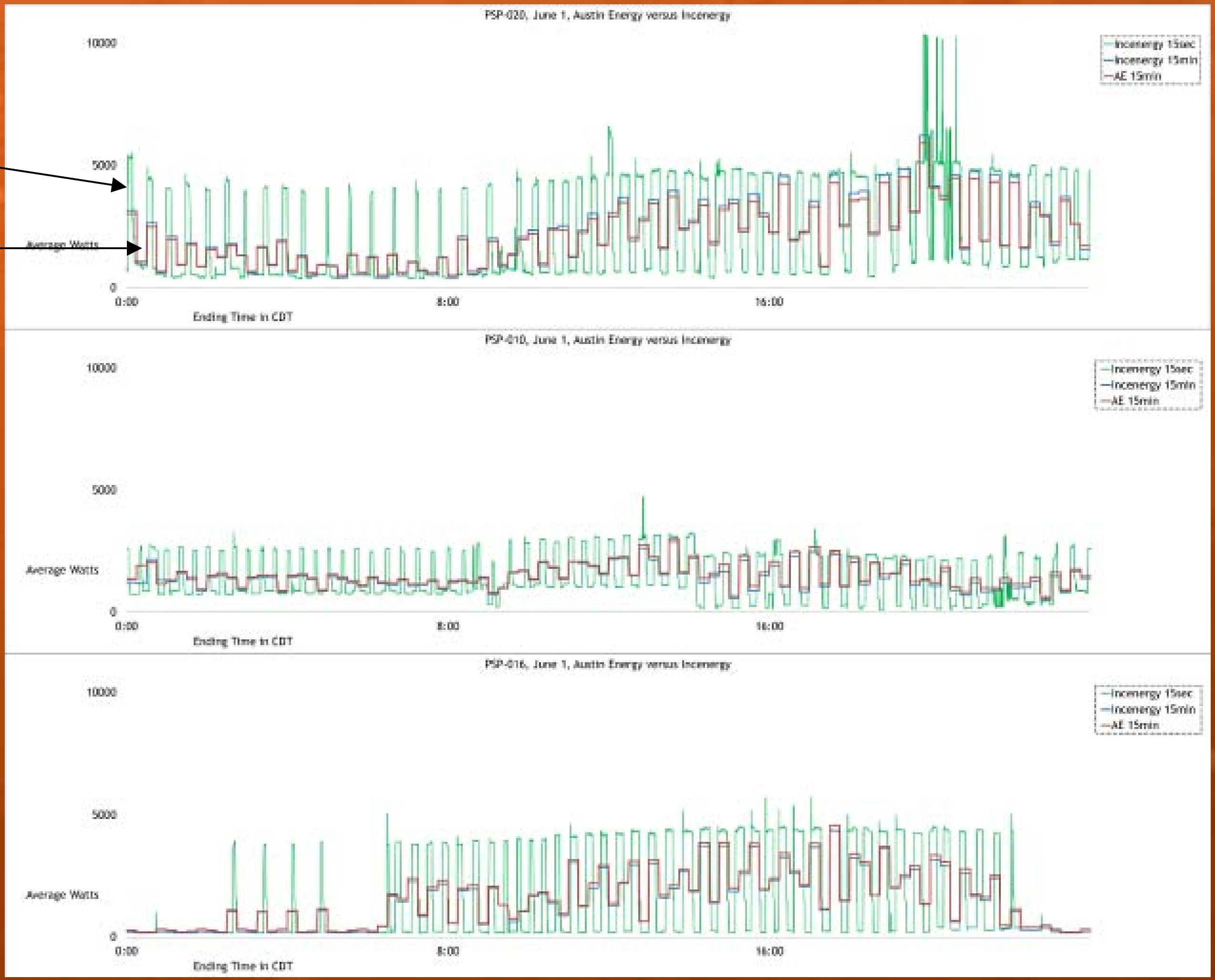
• Special focus is on electric vehicles (EVs) charging, PV power generation and energy storage management.

Residential-level Research

• HEMS averaging rate

15'' rate measurement

Conventional measurement (15' rate)

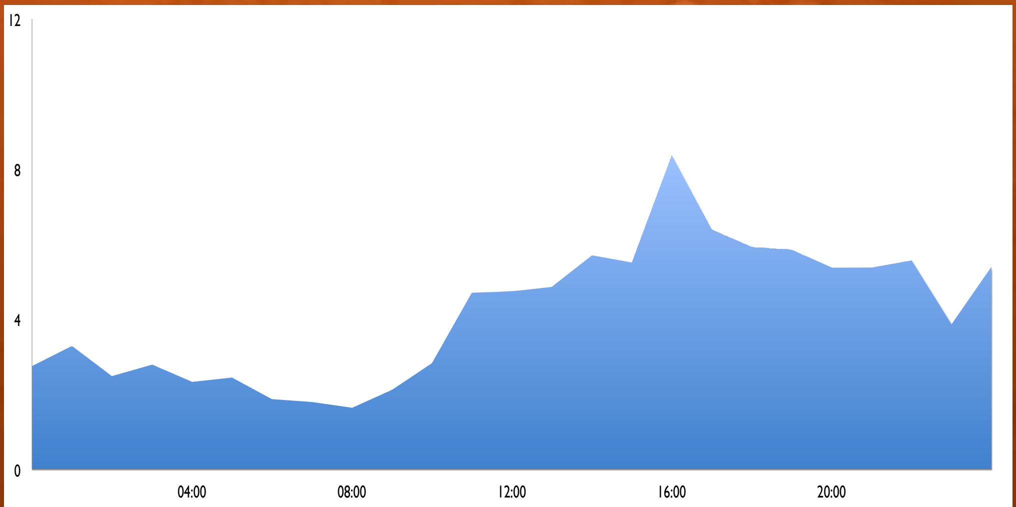


- **Observations:**
  - **Energy consumption is the same but power consumption is not the same.**

Residential-level Research

- Varying time resolution (60 minutes)

- What is the optimal time resolution to meet the energy management goals?
- Consequences affecting data storage and processing.
- Lessons to be used for load pattern recognition and HEMS management algorithms.



Source: Scott Hinson

Residential-level Research

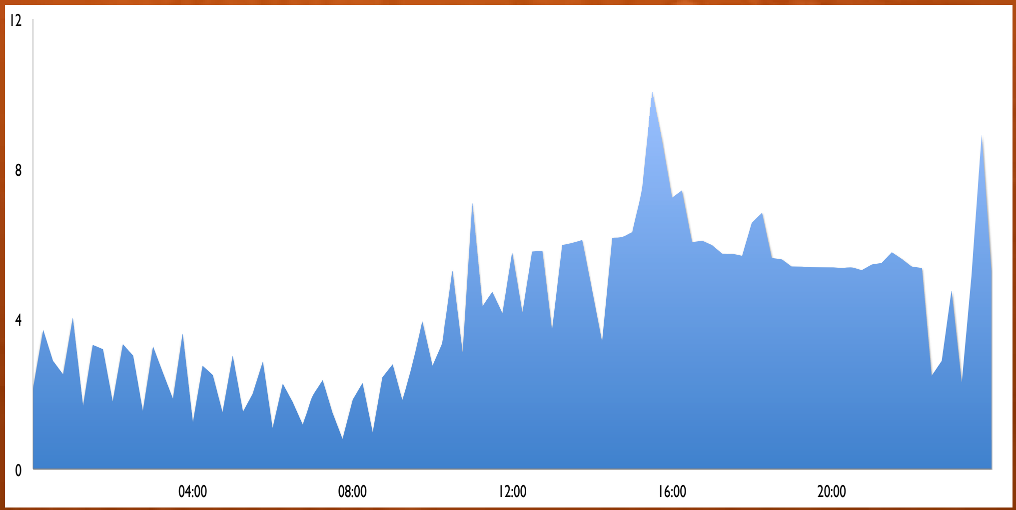
• Varying time resolution (15 minutes)

• What is the optimal time resolution to meet the energy management goals?

• Consequences affecting data storage and processing.

• Lessons to be used for load pattern recognition and HEMS management algorithms.

Source: Scott Hinson



Residential-level Research

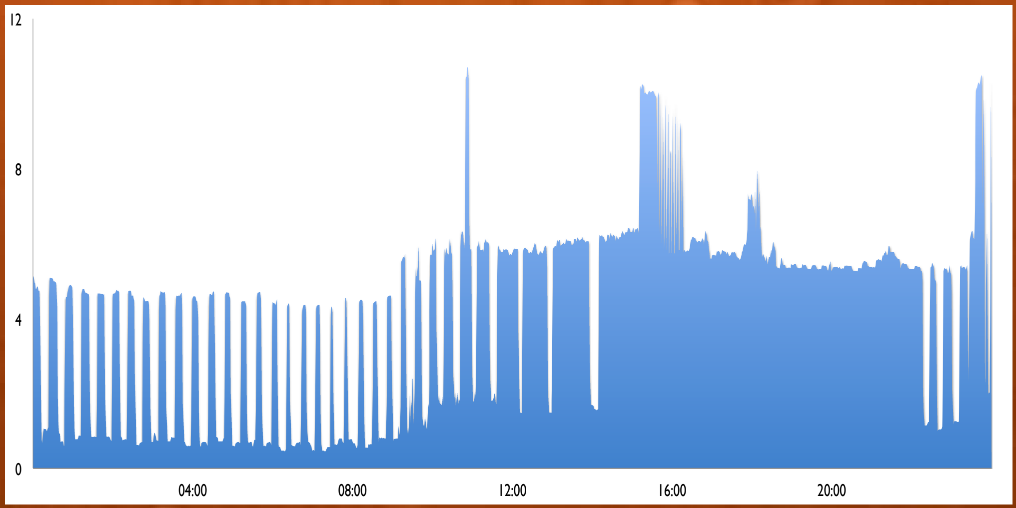
• Varying time resolution (1 minute)

• What is the optimal time resolution to meet the energy management goals?

• Consequences affecting data storage and processing.

• Lessons to be used for load pattern recognition and HEMS management algorithms.

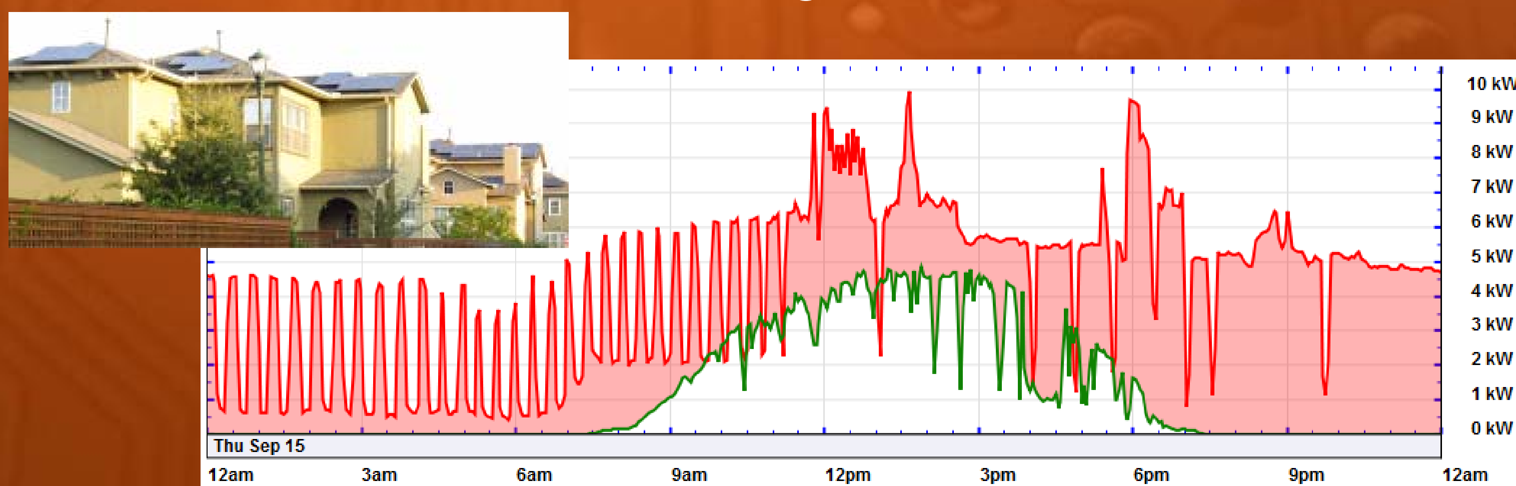
Source: Scott Hinson



Residential-level Research

• PV power generation

• Factors to be assessed:
  • Relationship with disaggregated loads (particularly a/c and EV)
  • Coordinated PV, EV, air conditioning and energy storage operation.
  • Effects of coordinated generation at neighborhood level.
  • Optimum orientation and usage patterns
  • Additional functionalities from local generation



Residential-level Research

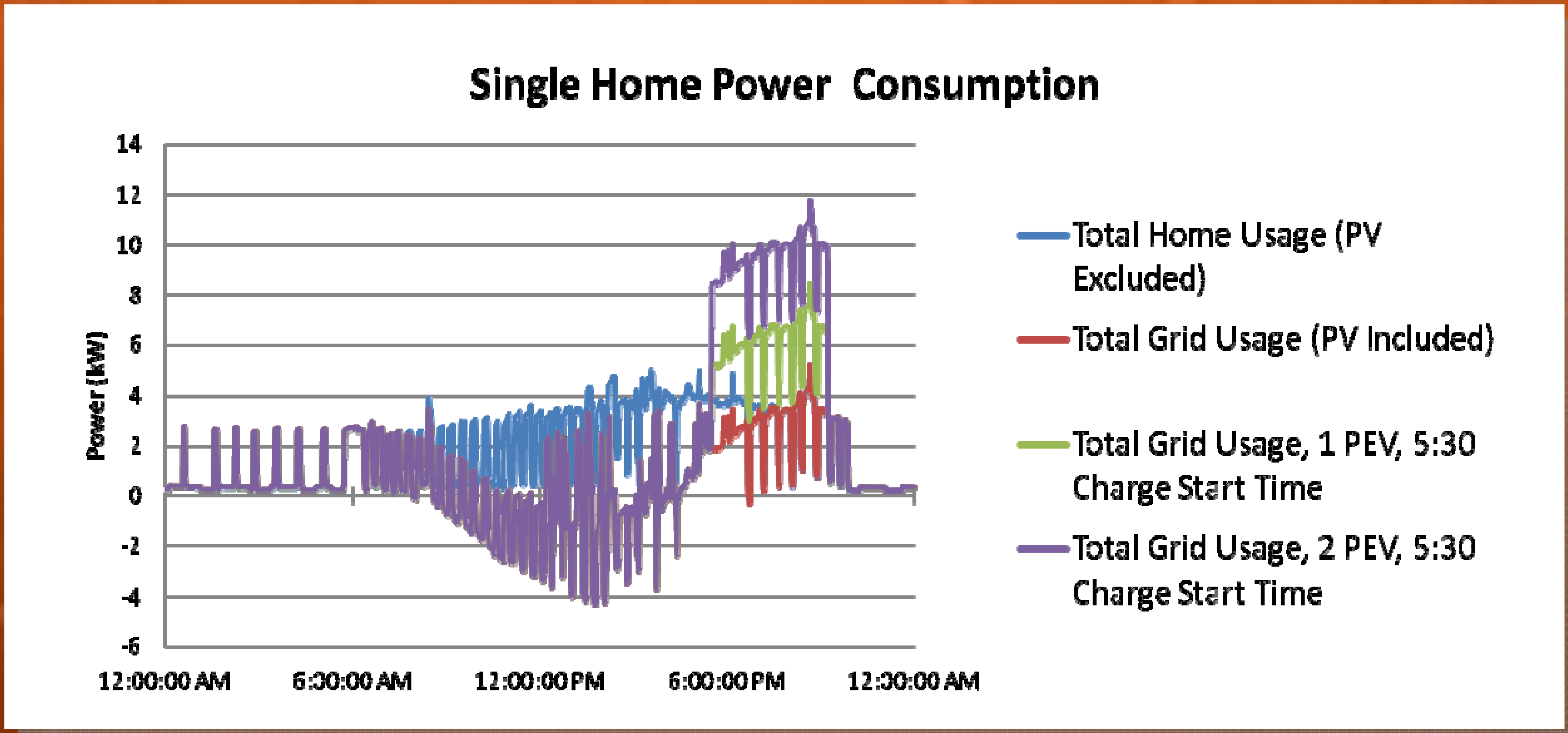
- Electric vehicles (EVs) charge management

- Two proposed research thrusts:
  - High-level: Wind-aligned PEV charging and aggregated PEV ancillary services
  - End-level: Intelligent charging algorithms.

- Research interests:
  - (PV + a/c) - HEMS - EV coordination in terms of communications and control.
  - EV communications security
  - Identifying EV charging profiles.

Residential-level Research

- EVs, air conditioning, PV coordination

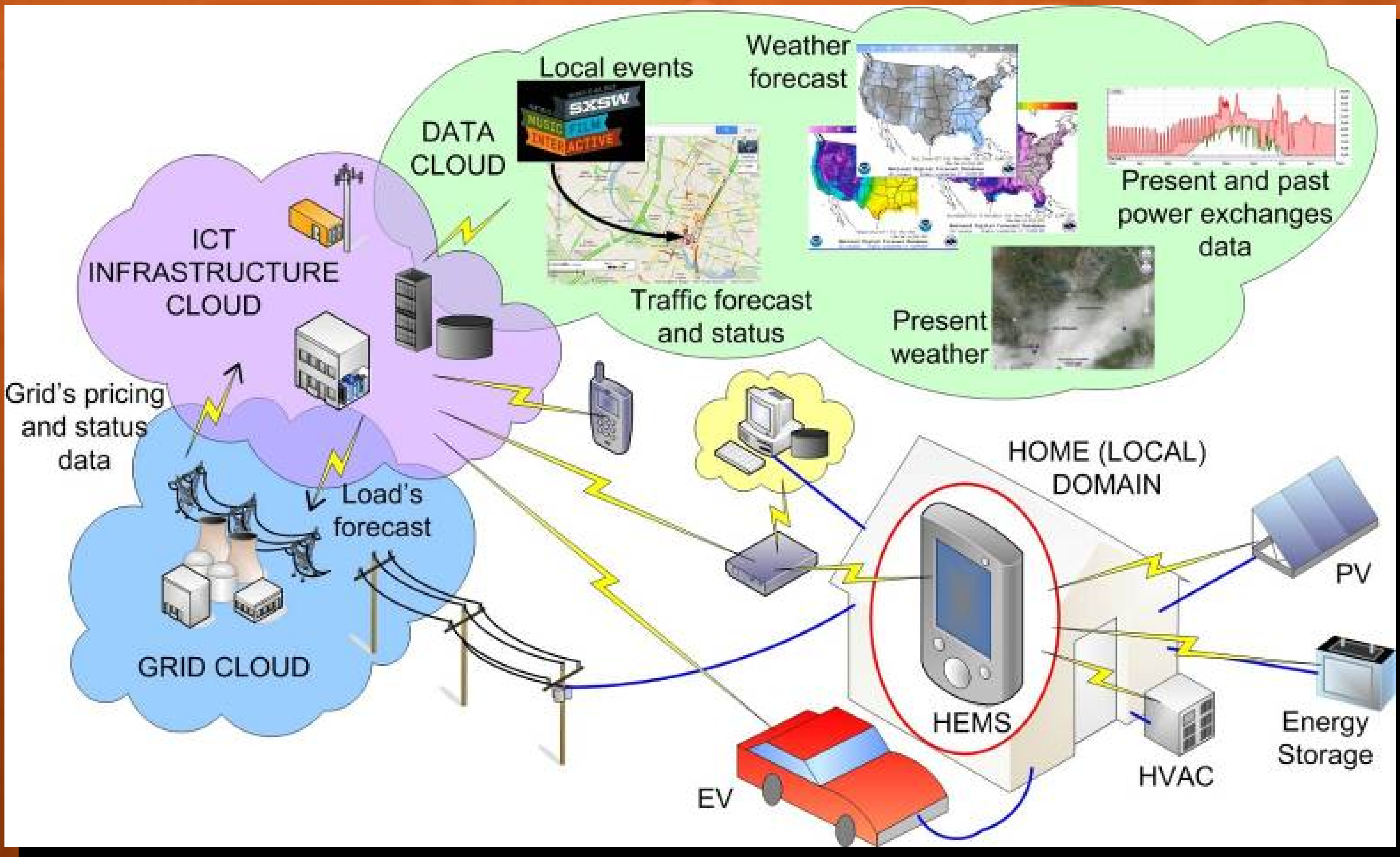


Weekday, August 2011

Source: Scott Hinson

Residential-level Research

- HEMS role in EV charge coordination



- Notice that grid and data clouds are separated

HEM Planning

- Interoperability

- Two levels:
  - Hardware (power architecture)
  - Software (communications and control).
- Two domains:
  - Internal, within home
  - External, with the grid and other surrounding infrastructures (e.g. natural gas, roads, and water)

Hardware Interoperability

- Interoperability (power architectures)

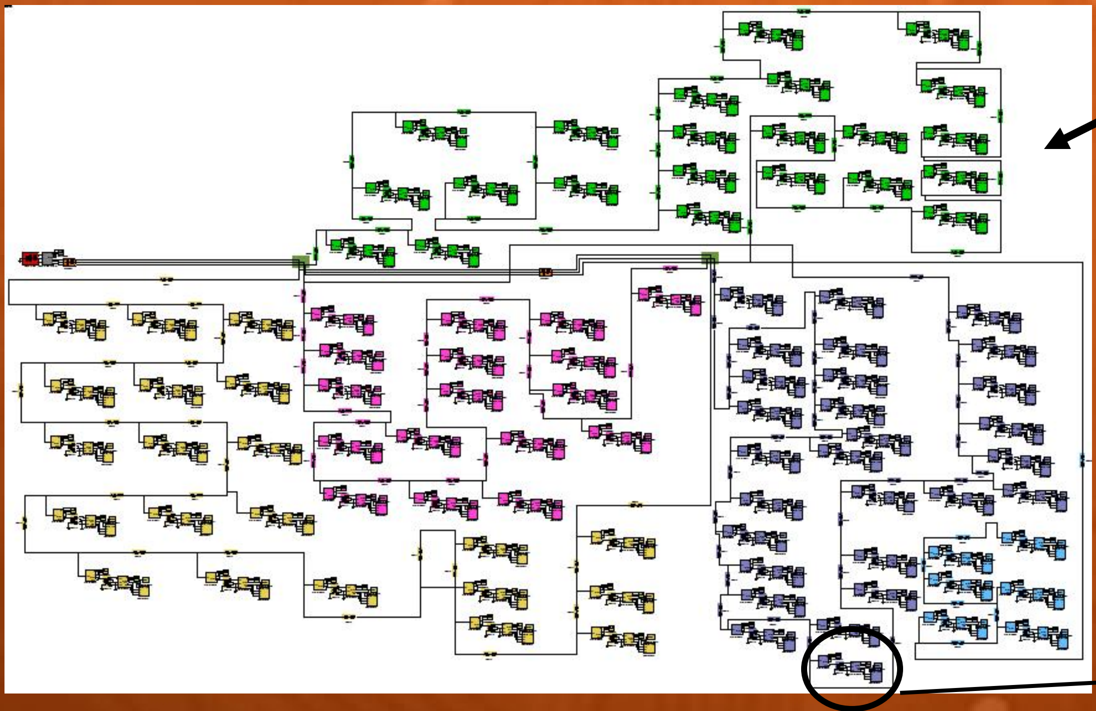
- dc elements:
  - Energy Storage
  - Local generation (PV, wind, fuel cells; at higher power levels microturbines).
  - Loads (computers, entertaining systems, lights, more energy efficient appliances and air conditioners, EVs).

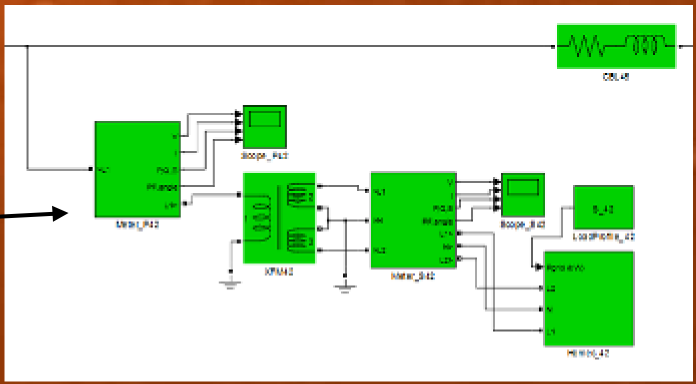
- ac elements:
  - The grid
  - Heating and conventional loads (lights, air conditioners).

Modeling

- Mueller area power distribution

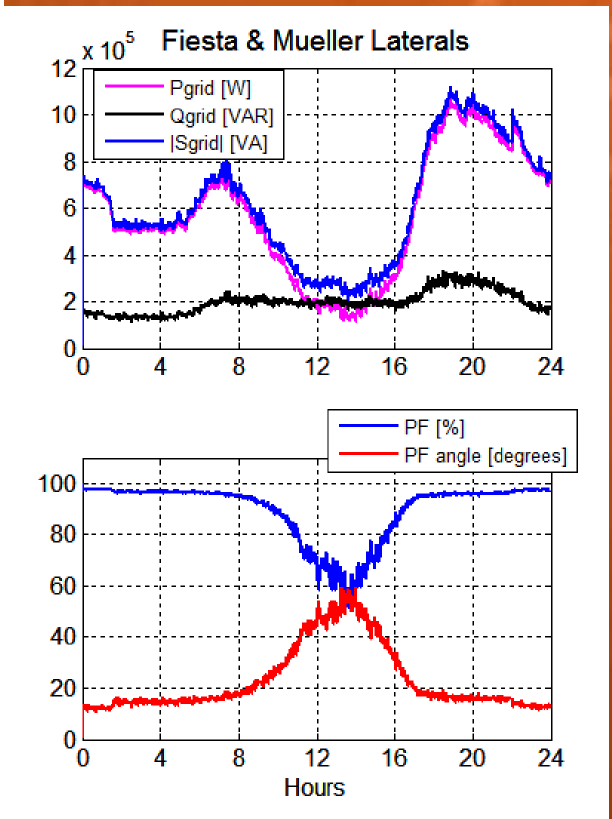
- Matlab/simpower-based
- Includes PV, EV and other assets

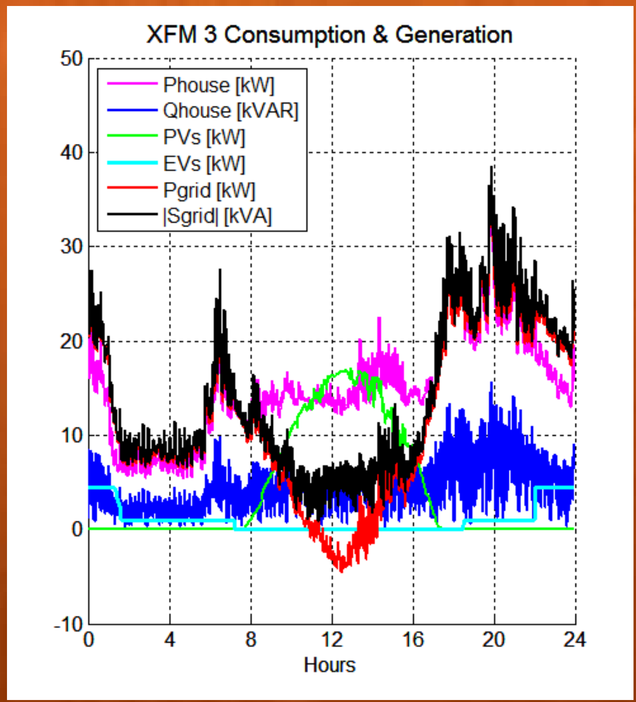


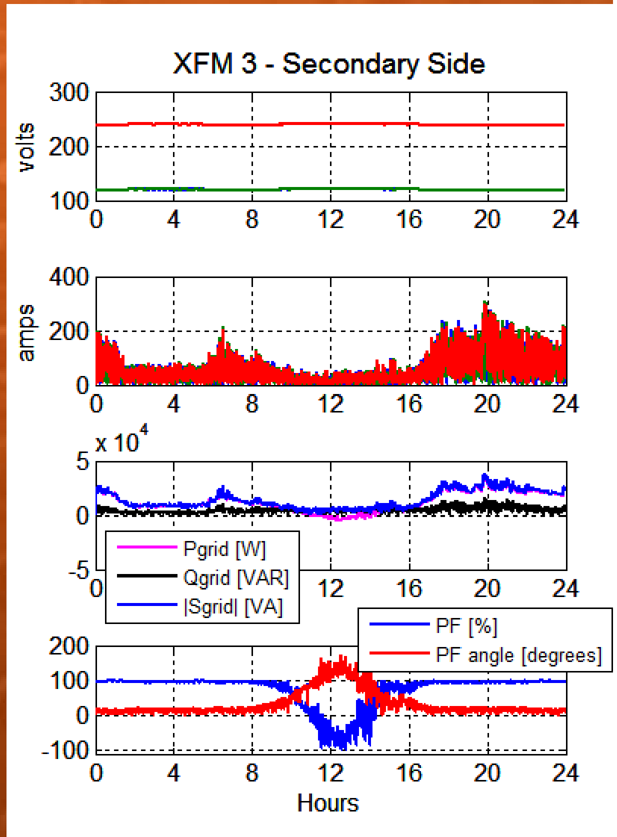


Modeling

- Mueller area power distribution
- Results



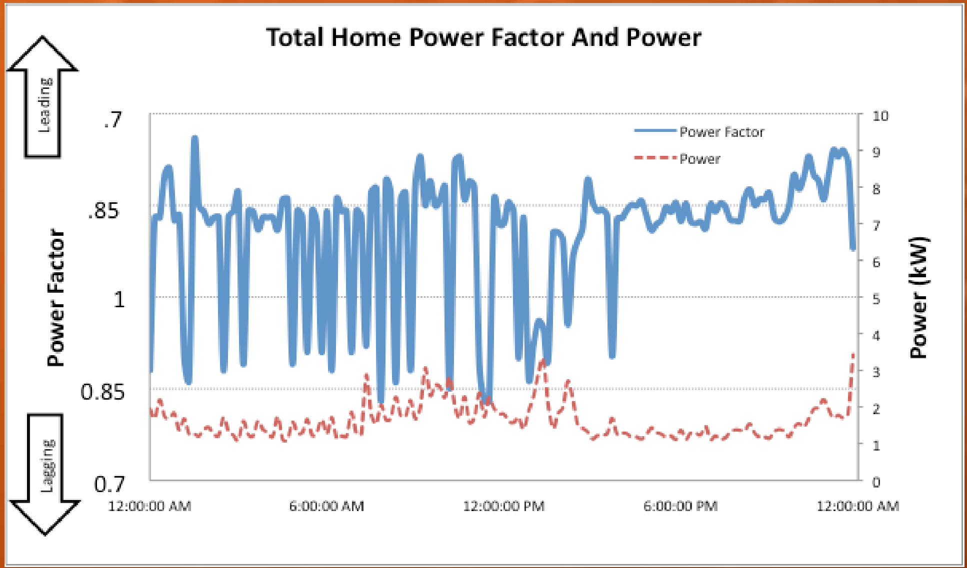




Hardware Interoperability

- Power factor

- Low power factor due to harmonic content and reactive power
  - Lights
  - Air conditioning



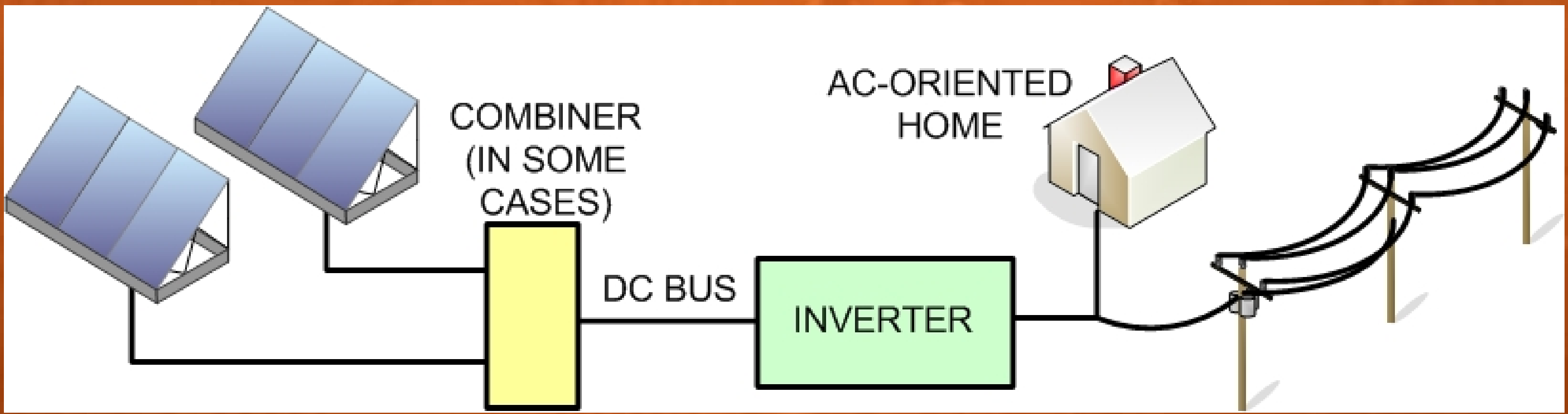
Source: Scott Hinson

- Interoperability issues:
  - PV inverters provide power at unity power factor.
  - PV generation assets may provide all real power needed in the neighborhood so the electric utility is left providing only harmonics and reactive power.

Hardware Interoperability

- PV integration

- Grid-tied (utility centered)

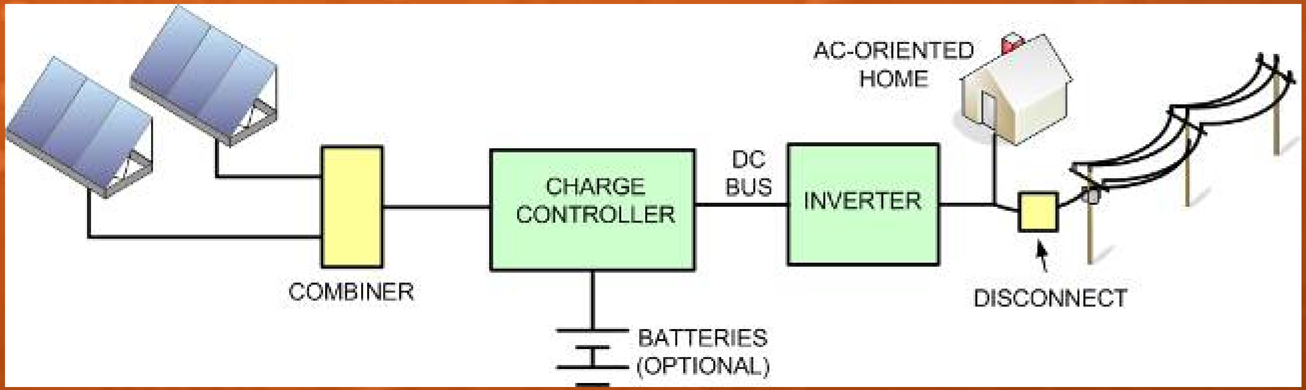


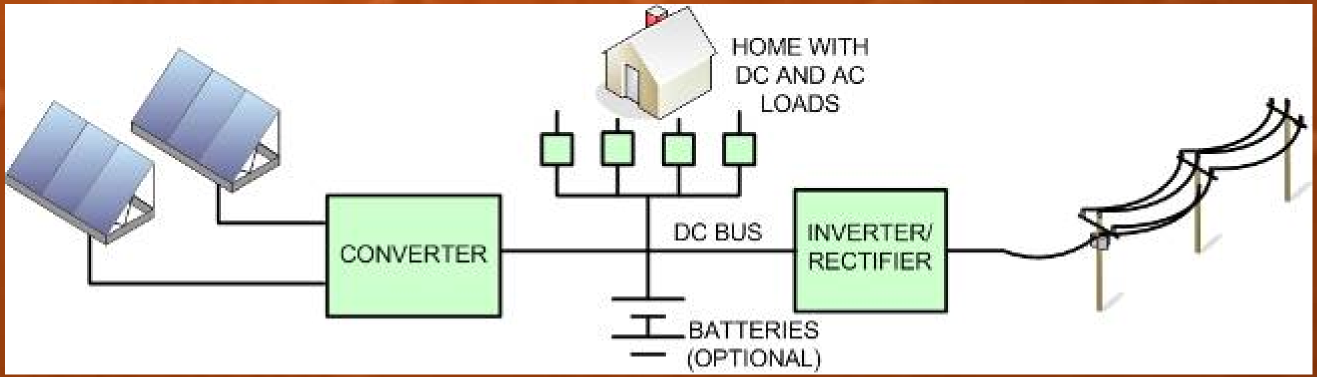
- Most widely used PV integration approach.
- PV and home operation subject to grid operation: Due to IEEE 1547, the inverter cannot power the home when the grid is not present.
- Power factor issues with high penetration of PV

Hardware Interoperability

- PV integration

- Customer centered approaches
  - More equal interoperable approaches (but far less common or inexistent):





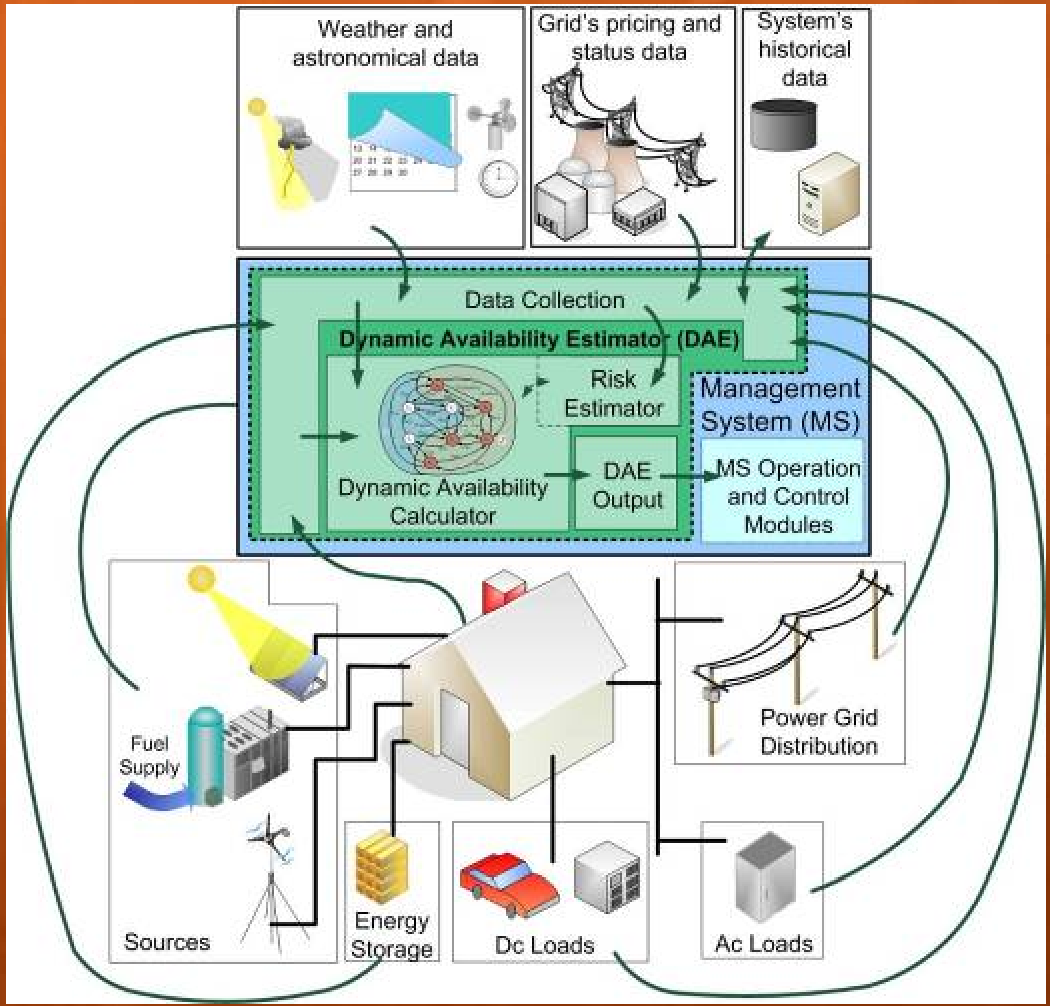
THE UNIVERSITY OF TEXAS AT AUSTIN

Emergency Operations

THE UNIVERSITY OF TEXAS AT AUSTIN Cockrell School of Engineering

- HEMS operation in disasters

- General architecture intended for operation during extreme events
- Communications may be limited.
- HEMS managing local resources and loads to optimize power availability

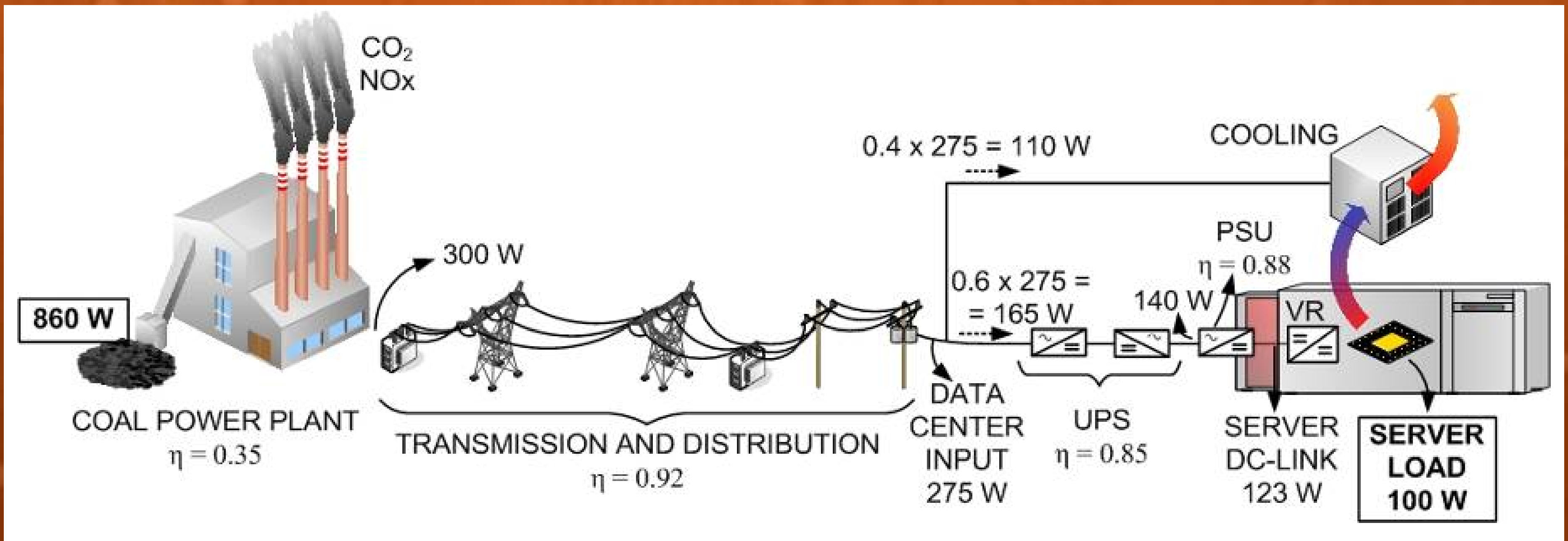


Data centers

- Issues in the conventional approach

- Data centers represent a noticeable fast increasing load.

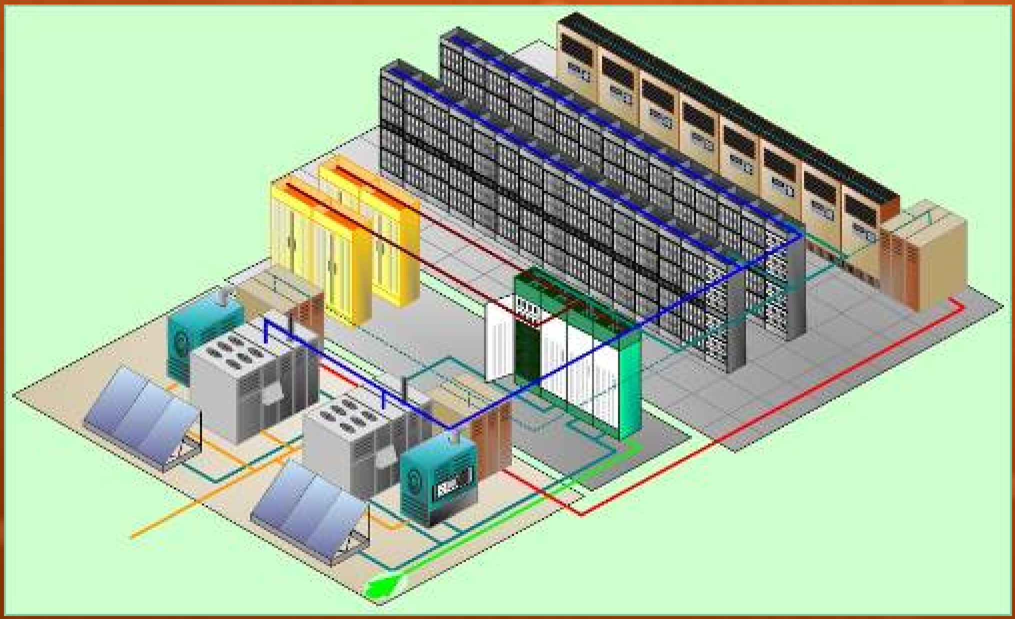
- Increasing power-related costs, likely to equal and exceed ICT equipment cost in the near to mid-term future.

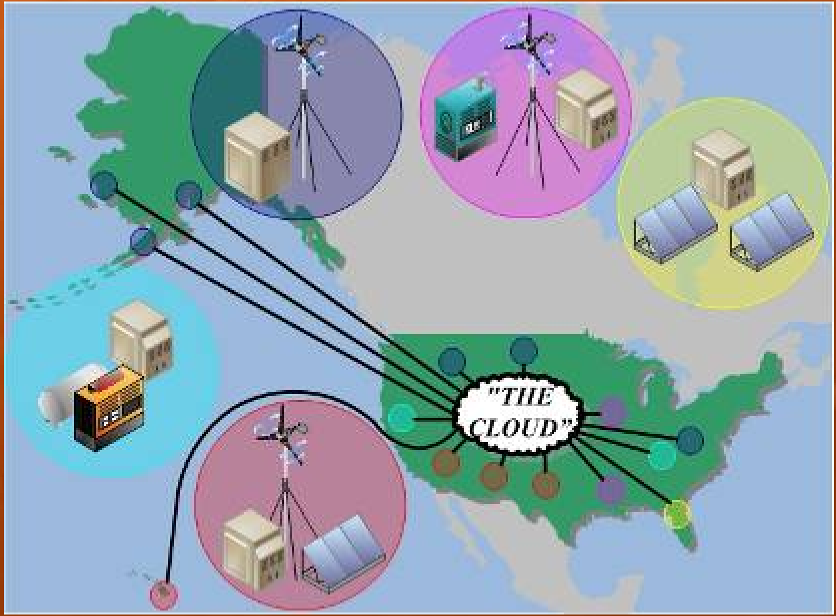


Data centers

- Solutions under study

- Analysis of power architectures for highly available and efficient data centers:
  - Large data centers with dc micro-grids
  - Stand alone and small distributed and modular data centers with photons used as a proxy for dispatchable electrons.

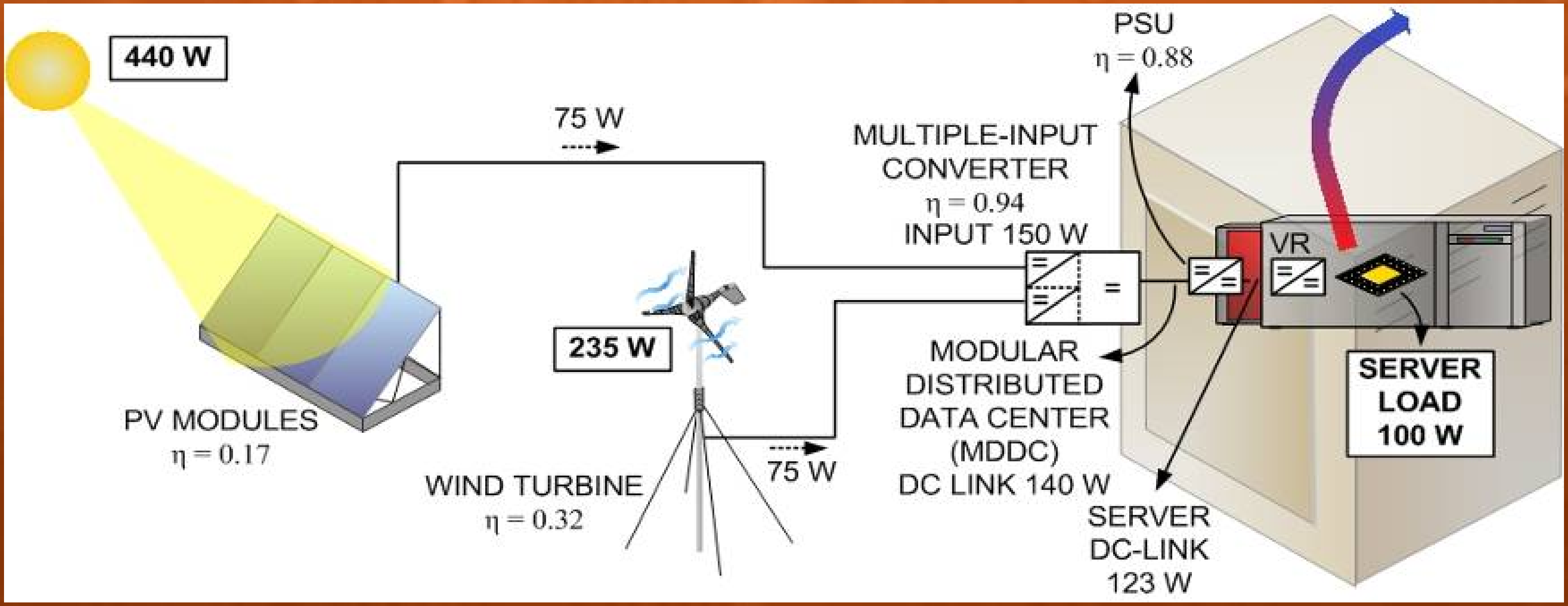




Distributed data centers

- Energy use - efficiency in new approach

- Energy is used more effectively.
- Generation inefficiencies is energy that is not harvested (i.e. converted), contrary to inefficiencies in conventional power plants which represent power losses.



Distributed data centers

• Advantages

• Cost savings: fiber optics costs several orders of magnitude less than electricity transmission lines cost.

• Reduced need for batteries

• DC power architecture

• Cooling infrastructure may be avoided

• Enable a higher penetration of renewables

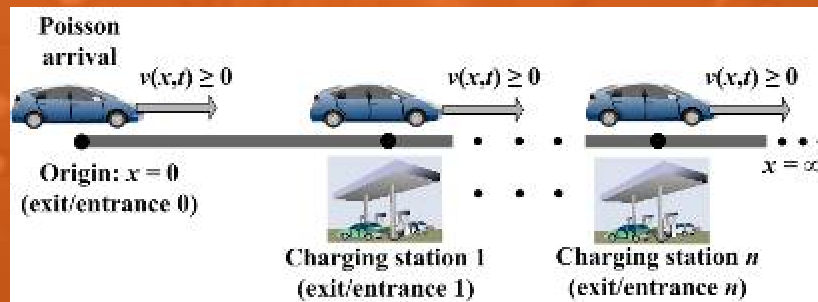
• More robust and secure system (both in normal conditions and in extreme events).

• Fully independent from the grid **or grid connected**.

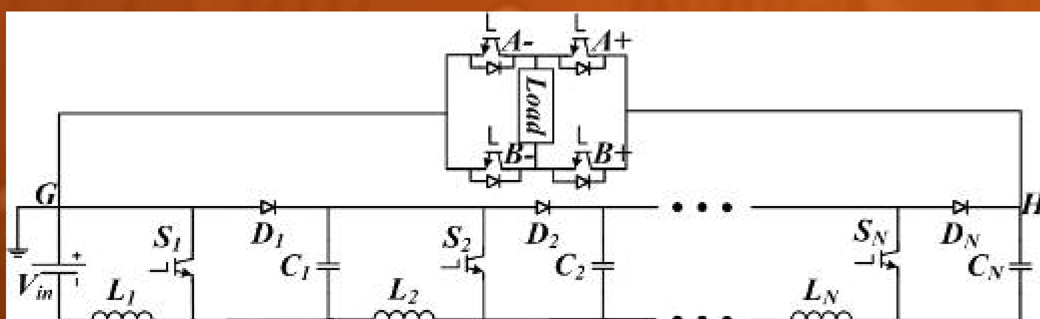
Other Relevant Topics

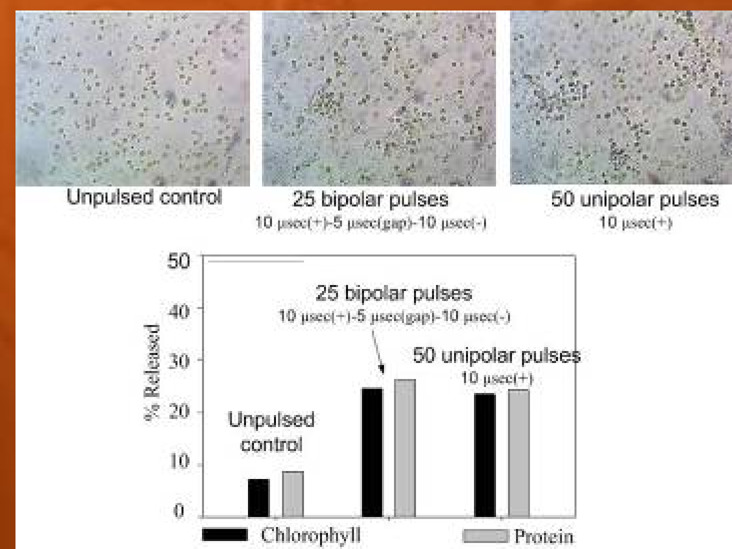
- Additional projects in power electronics systems at UT

- Modeling of charging demand from electric vehicles



- Power supply to extract oil from algae cells





A. Kwasinski Profile

• **Previous 10 years experience in telecom power industry (significant part of it in Lucent Technologies Power Systems – now Lineage / GE Energy).**

•**Publications sample**

✓ A. Kwasinski, "Identification of Feasible Topologies for Multiple-Input dc-dc Converters," *IEEE Transactions on Power Electronics*, vol. 24, no. 3, pp. 856-861, March 2009.

✓ S. Bae and A. Kwasinski, "Dynamic Modeling and Operation Strategy for a Microgrid with Wind and Photovoltaic Resources," in press IEEE Transactions on Smart Grid

✓ A. Kwasinski and C. N. Onwuchekwa, "Dynamic Behavior and Stabilization of dc Micro-grids with Instantaneous Constant-Power Loads." *IEEE Transactions on Power Electronics,* in print.

✓ A. Kwasinski "Quantitative Evaluation of dc Micro-Grids Availability: Effects of System Architecture and Converter Topology Design Choices." *IEEE Transactions on Power Electronics,* in print.

✓ A. Kwasinski, P. T. Krein and P. Chapman, "Time domain Comparison of Pulse-Width Modulation Schemes," in *IEEE Power Electronics Letters*, vol. 1, no. 3, pp. 64-68, Sep. 2003.

✓ A. Kwasinski, V. Krishnamurthy, J. Song, and R. Sharma, "Availability Evaluation of Micro-Grids for Resistant Power Supply During Natural Disasters," in press IEEE Transactions on Smart Grid.

✓ J. Song, V. Krishnamurthy, A. Kwasinski, and R. Sharma, "Development of a Markov Chain Based Energy Storage Model for Power Supply Availability Assessment of Photovoltaic Generation Plants," in press IEEE Transactions on Sustainable Energy

A. Kwasinski Profile

- **Relevant awards**
  - ✓ 2011 IBM Faculty Innovation Award
  - ✓ 2009 NSF CAREER Award
  - ✓ 2007 Best Paper Award at INTELEC
  - ✓ 2005 Joseph Suozzi Fellowship
- **Lab capabilities and research group**
  - ✓ Currently supervising 8 graduate students
  - ✓ Power electronics lab developed by the researcher and fully prepared for advanced research in power electronics and power related systems. Some relevant equipment:
    - ✓ Advanced power analyzer and oscilloscopes
    - ✓ Multi-kW level loads and power sources
    - ✓ Computers for simulations and analysis
    - ✓ Dynamometer bed for electric motor cycle study.