**EE 4223/5223 - Lecture 41** Wednesday April 20, 2011

## Ongoing List of Topics:

- URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
- Term Project - Due Friday (remote students can negotiate extension)
  - Local presentations: Mon 2-5pm; EERC B45. Will ask for 6 volunteers.
- Gen Protection - Ch. 8, Basic Protection issues (summary from prev lectures)
  - IEEE Publication 95TP102 - Prot of Synch Gens
  - IEEE C37.102 - Guide for AC Generator Protection
  - IEEE C37.101, C37.106 - Ground Protection, Abnormal Freq Protection
  - Grounding Issues
  - Notes from adjunct faculty, example
  - Out-of-step issues - see also Kundur's text – EE6210
- An extreme example of stray voltage (neutral current return thru gnd paths)
- Motor Protection
  - Armature - similar strategies as with Synch Machines
  - Bearing Temp, vibration. Other issues - See Ch.11
- SCADA basics, transducers, scaling factors for relays and SCADA
- Smart Grid - Focus today

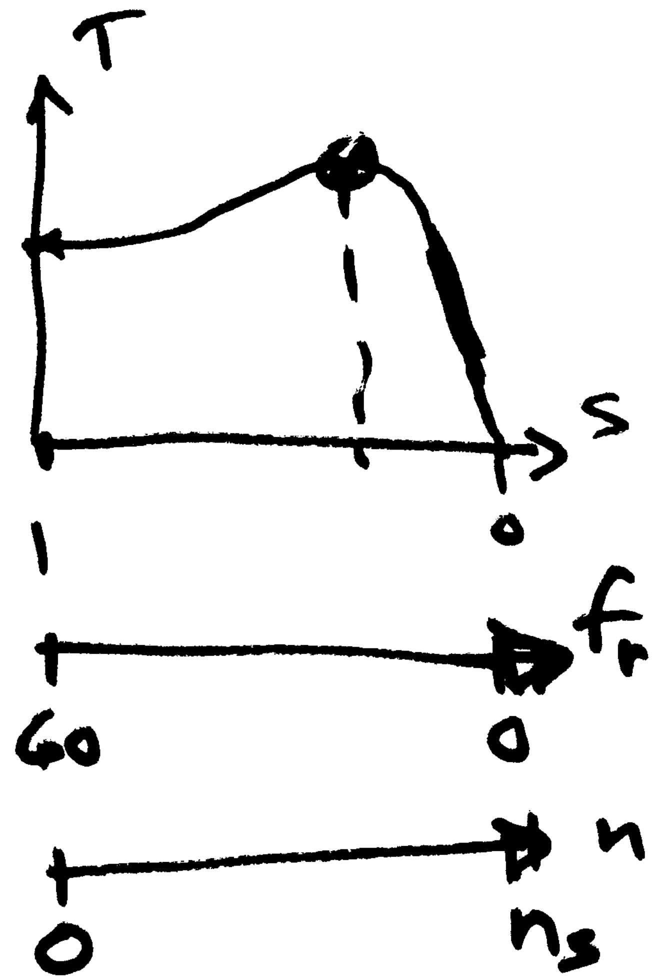
Next/Last:

- Basic DSP relay algorithms – convert samples waveforms into phasor Vs and Is
- Real-time Communications for protection & control, IEC 61850

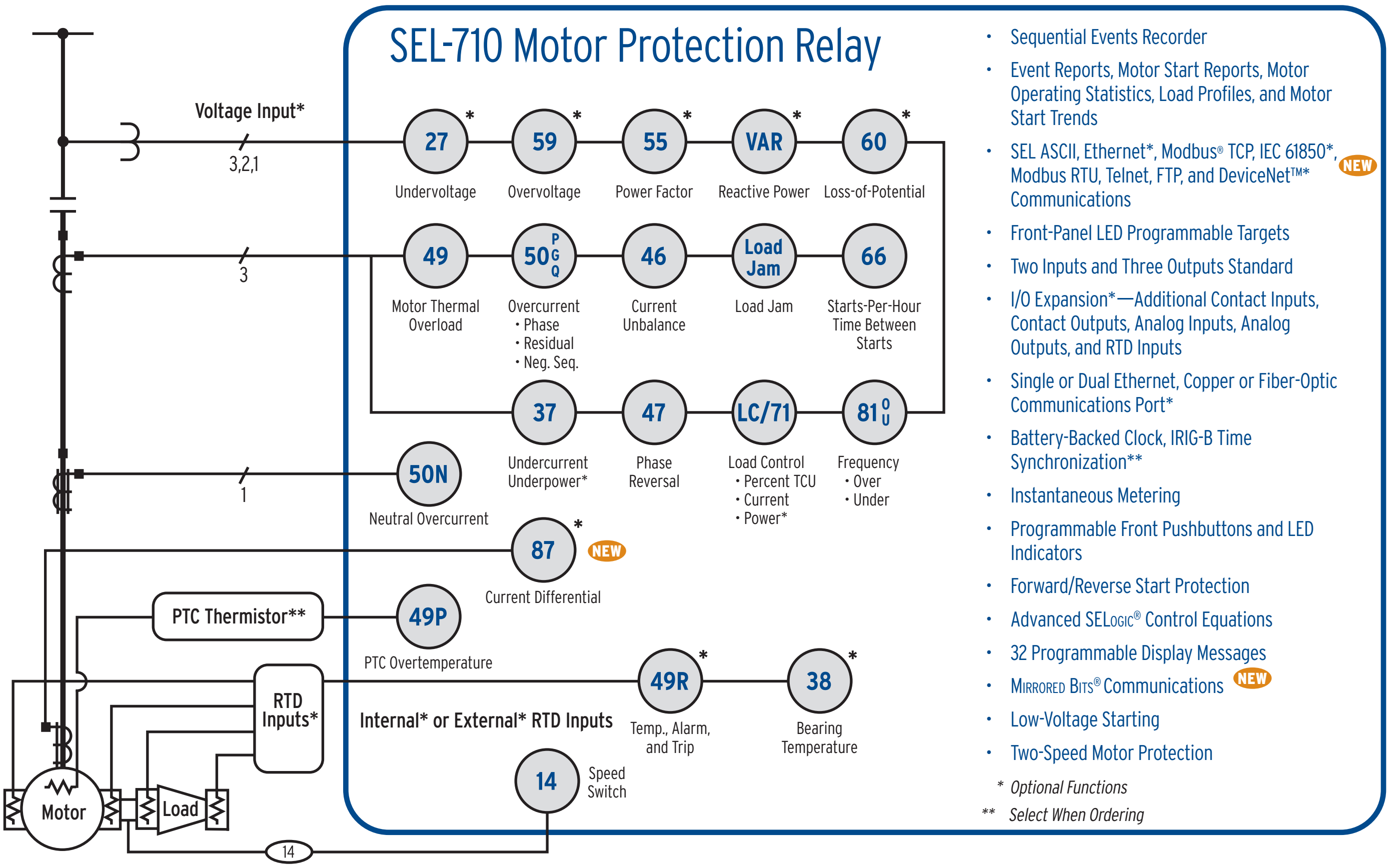
# Motor Protection System

- Overloading – heat/thermal
- Vibration – Bearings
  - $3\phi$ $T_{ind} = K$
  - $1\phi$ $T_{ind} \neq K$ (<5 HP)
- Motor Starting, Motor Drives

$$\frac{V}{Hz}$$

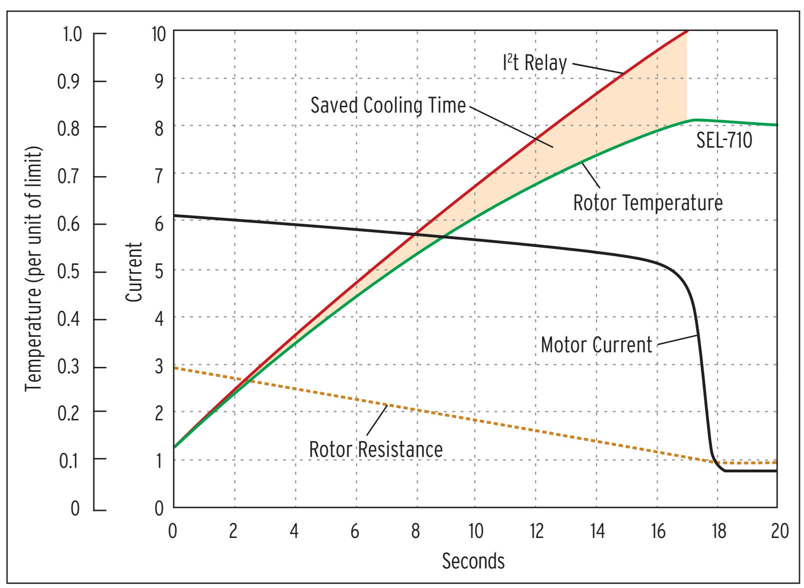


## Functional Overview




## AccuTrack™ Thermal Model

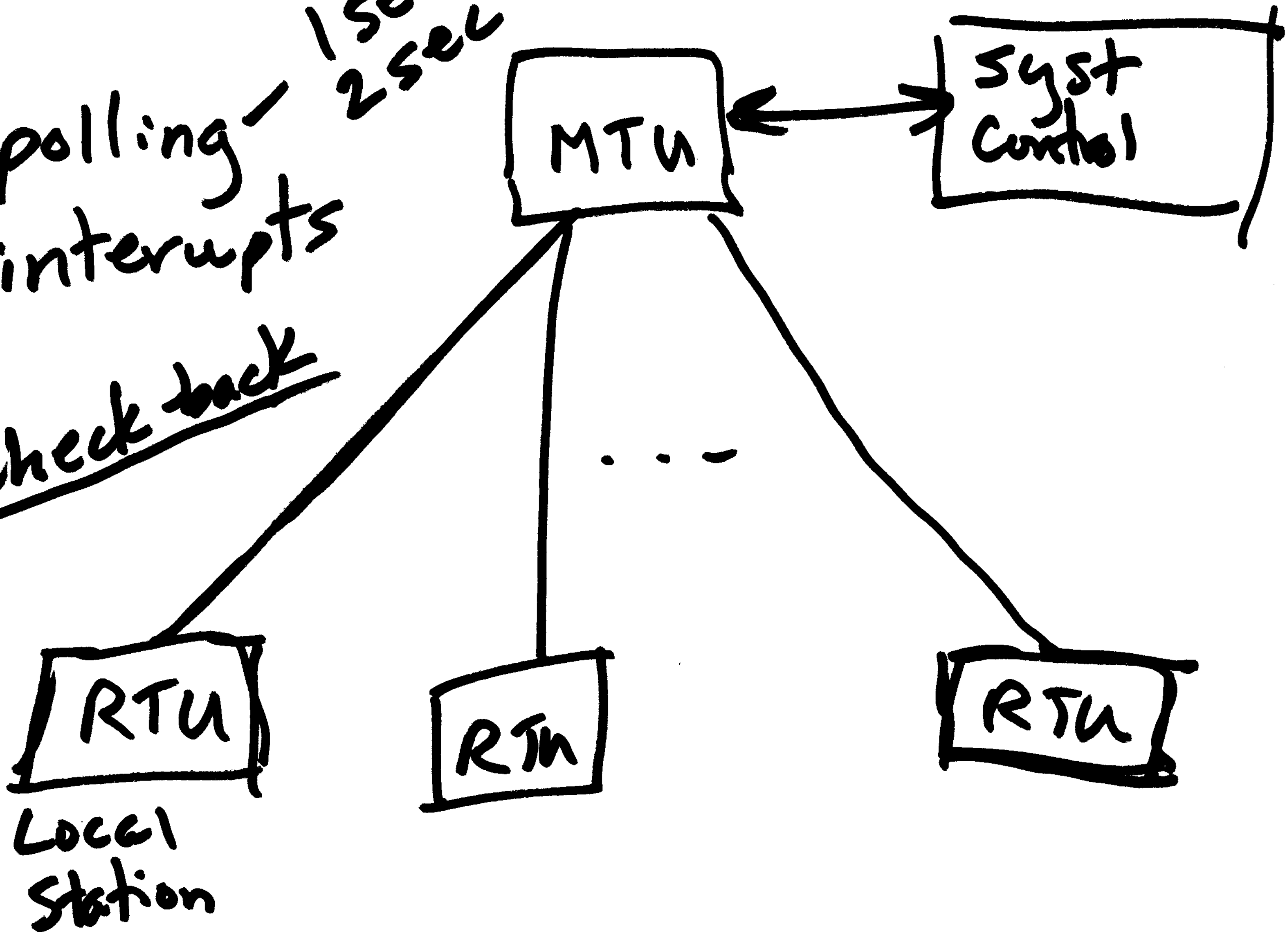
The SEL-710 Motor Protection Relay takes the next logical step in motor monitoring and control. While other motor relays assume a constant value for rotor resistance, the SEL-710 dynamically calculates motor slip and uses this information to precisely track motor temperature using the AccuTrack Thermal Model. Rotor resistance changes depending on slip and generates heat, especially during starting, when current and slip are highest. If your motor protection uses a constant rotor resistance for thermal protection, it could be off by a factor of three or more. By correctly calculating rotor temperature, the AccuTrack Thermal Model reduces the time between starts. It also gives the motor more time to reach its rated speed before tripping.




*Accurate thermal modeling provides protection that maximizes motor availability while providing excellent protection from damage.*

## SCADA – Monitoring & Control

- polling – 1 sec – 2 sec
- interupts
- Check back



**RTU** - I/O

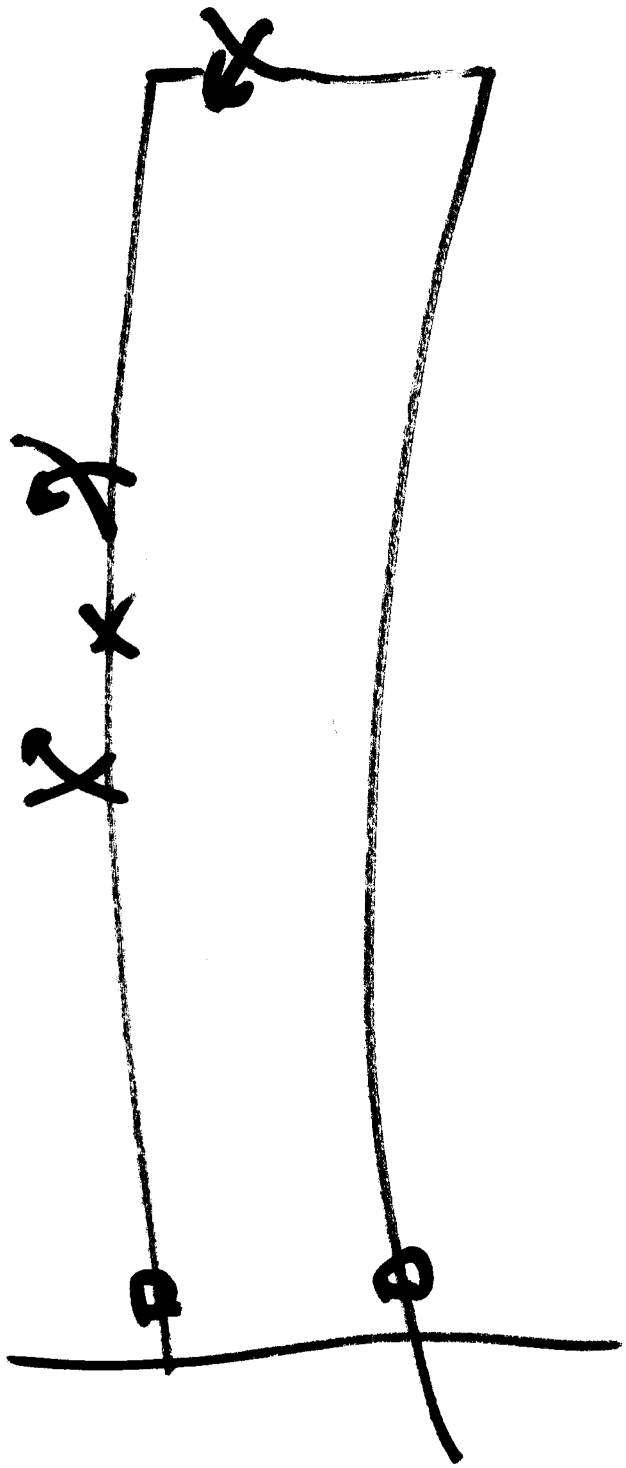

**ANALOG:** (INPUTS)
- Voltage
- Current
- Watts, Vars
- Temp
- Pressure
- etc.

A/D
- Bits
- Dynamic Range

**Status** (inputs)
- 52a, 52b

open/close
off/on
local/remote

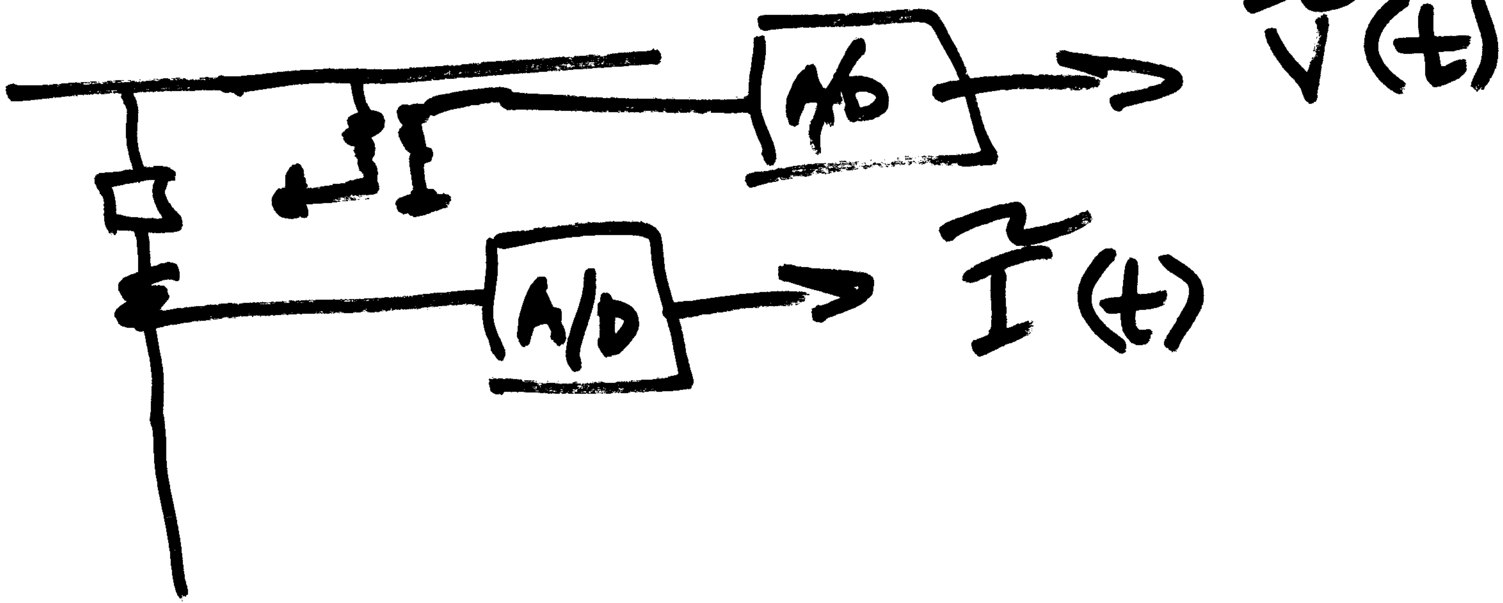
**Control** output
- Trip/Close; PSET
- On/off. - LTC



## Generation 4

- "Smart Grid"
- IEC 61850
- Embedded Processors
- Intranet (Cybersecurity)
- NERC CIP stds.

- Synchrophasors – <u>high-speed</u>
- PMU – low speed




- Vector processor ←

- WAM, WAMPAC

# Smart Grids and Micro-grids

*What are they really?*

by
Bruce A. Mork, Ph.D., P.E.
Wayne W. Weaver, Ph.D., P.E.
Department of Electrical & Computer Engineering

Presented at the Minnesota Power Systems Conference
Brooklyn Center, MN
November 3-5, 2009

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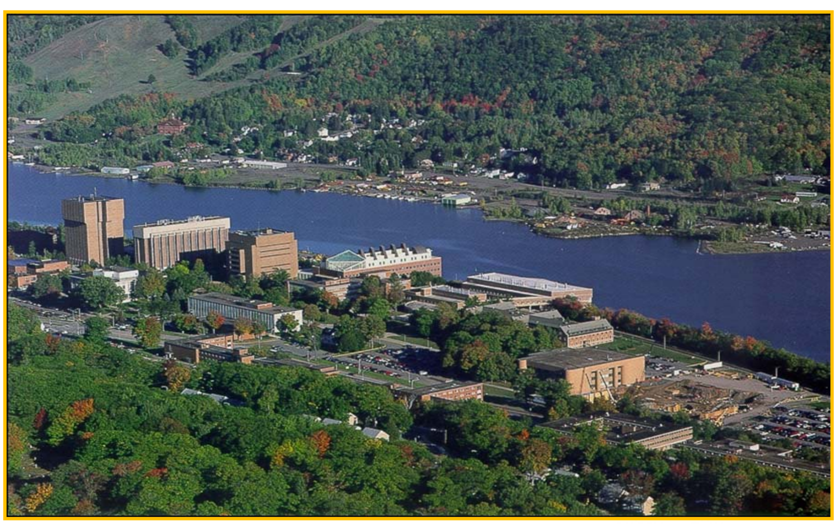
# Michigan Tech



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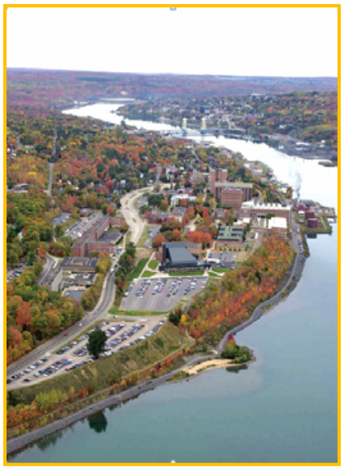




# Quick Overview of EE Power

- Six faculty, 35 grad students, 60 UGs
- Responding to workforce needs:
  - 14 online courses: EE3010 … EE6210
  - Online MSEE (~40 enrolled)
  - Online certificate, advanced certificate (~25 enrolled)
  - DOE Transportation electrification program
- State-of-the-art labs
  - Relaying
  - Power Electronics
  - Motor Drives
- Power & Energy Research Center
  - Multi-disciplinary, industry partners

# Motivation for this presentation

- Steadily increasing media buzz, little substantive information.
- Only a small subset of possibilities are being discussed. Smart meter ≠ smart grid.
- Little practical sense for what is possible:
  - a) now, and b) in the foreseeable future, and
  - What are the technology and financial bottlenecks?
- Since this presentation was scheduled,
  - IEEE PES General Meeting in Calgary
  - More useful info recently published
  - Mipsycon, Monday Seminar, Thursday Tutorials



# How do *<u>you</u>* define Smart Grid?

- Wikipedia: …*delivers electricity from suppliers to consumers using digital technology to control appliances at consumer's homes to save energy, reduce cost and increase reliability and transparency.*
- Green Energy Act (Canada): *A nickname for an ever-widening palette of utility applications that enhance and automate the monitoring and control of electrical distribution.*
- DOE: *The Smart Grid transforms the current grid to one that functions more cooperatively, responsively and organically.*

## Engineer's Definition

- That depends…
- Basically: embedded processors + sensors + data sharing, communications & distributed control. Generation 4 or "G4."
- Policy-makers & media: smart meters and energy marketing.
- Transmission/operations: wide-area monitoring & control & protection, special switching ops.
- Distribution: automation, reliability, time of day metering, integration of DR, renewables.

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## Components of a Smart Grid

- Hardware
  - Sensors, Embedded processors
  - Integration with other hardware
- Basic Software
  - SCADA, Energy management
  - Vector processors
- Communications
  - Slow (existing SCADA or EMS, more or less)
  - High-speed, high-bandwidth (need to develop)

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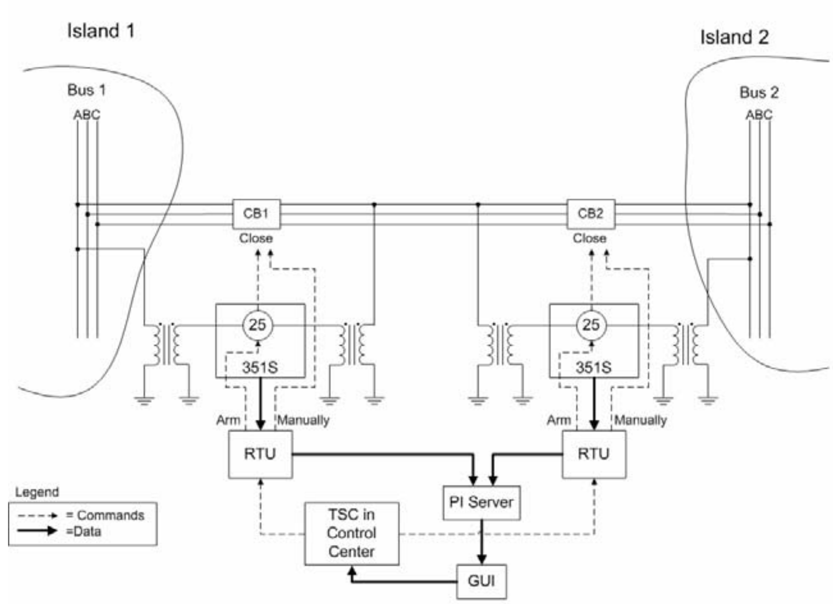
# Transmission Applications

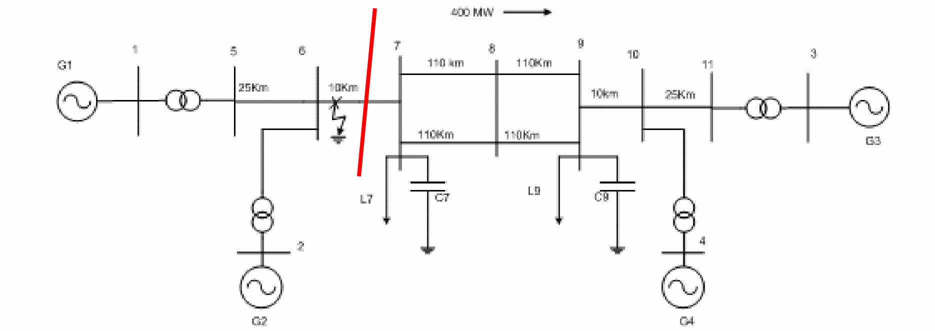
- Phasor measurement units (PMUs) and synchrophasors.
- Grid integration of renewables,
- Advanced metering, operations
- Wide Area: WAM, WAC, WAMPAC
  - Emergency control
  - Voltage Stability: Dynamic VAr control, avoiding voltage collapse
  - Angle Stability: Load shedding, Intelligent system separation




System restoration: remote tie-line closing.

# Emergency Control

(figure from Kundur)

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# Distribution Applications

- AMI - Application of smart meters
- Real-time pricing
- Demand side management
- Distribution automation
  - Automatic high-speed transfer, reconfiguration
- DR (Distributed Resources), DG (Dist Gen)
- CES (Community Energy Storage)
- Optimizing efficiency, reliability, carbon footprint

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## On Customer Side of Meter

- Load Management (coordinated w/utility)
- *Integration of energy resources as **micro-grid***
  - *Interconnection with Utility*
  - *Interruptible Loads (water heater, heat, AC)*
  - *Electric or hybrid-electric vehicle*
  - *Generation: solar, wind, micro-hydro*
  - *Energy storage: battery*
  - *Optimal control according to goal of customer*

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## Requirements, Concerns

- Communications bandwidth for "fast" wide area applications
- Time delays, GPS time-tagging
- Interoperability
- Information overload, database sharing
- Cyber security
- Information security, privacy
- Complexity, reliability of technology applications themselves.

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# References

1. U.S. Department of Energy, The Smart Grid: An Introduction. http://www.oe.energy.gov/SmartGridIntroduction.htm
2. IEC TC57: IEC61850 architecture for substation automation, IEC 61970/61968 — the Common Information Model CIM.
3. IEEE C37.118 – synchrophasors
4. IEEE P2030 Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System, and End-Use Applications and Loads. http://grouper.ieee.org/groups/scc21/2030/2030_index.html
5. IEEE Power & Energy Magazine, Sept/Oct 2009, "Smart Grid: What is it Really"
6. IEEE Potentials Magazine, Sep/Oct 2009, "Cascading Power Grid Failures"
7. ASEE Prism, Oct 2009, "Untangling the Grid."



# Observations

- It's early on in a new series of technologies. Vendors competing for market share, new standards are developing.
- Try to take a holistic view of the system and *interaction/interoperability*
  - Generation
  - Transmission
  - Distribution
  - Customer side: microgrid, green buildings

# On Customer Side of Meter

- Load Management (coordinated w/utility)
- *Integration of energy resources as **micro-grid***
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# What is a Micro-Grid?

- Small, independent power system
- Increased reliability with distributed generation
- Increase efficiency with reduced transmission length and CHP
- Easier integration of alternative energy sources
- PROBLEM: Control
  - Damping/Stability
  - Islanding
  - Load sharing
  - Energy Management

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# Components of a Microgrid

- Defining
  - Multiple Distributed Generation Points
  - Control System / Energy Management
- Additional
  - Utility Interconnection Switch – Point of Common Coupling (PCC)
  - Energy Storage



# Microgrid Application

- Communities/Neighborhoods
- Corporate/Academic Campuses
- Buildings
- Military base camps
- Naval Systems

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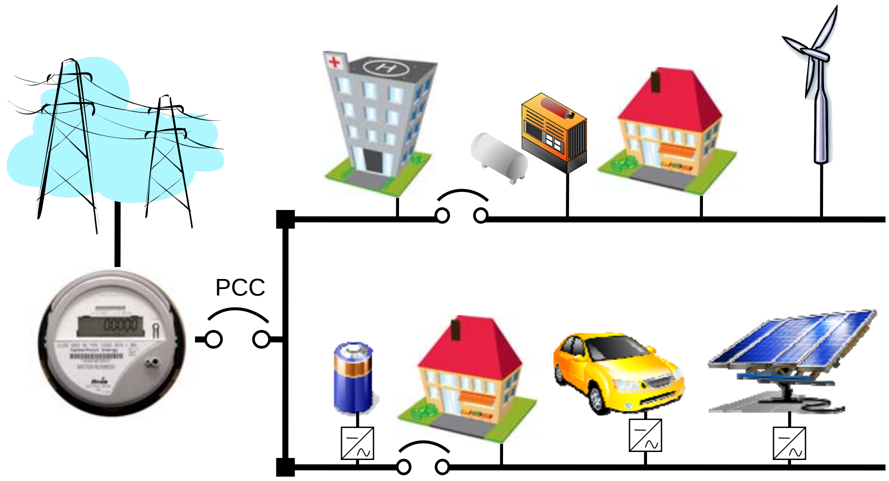
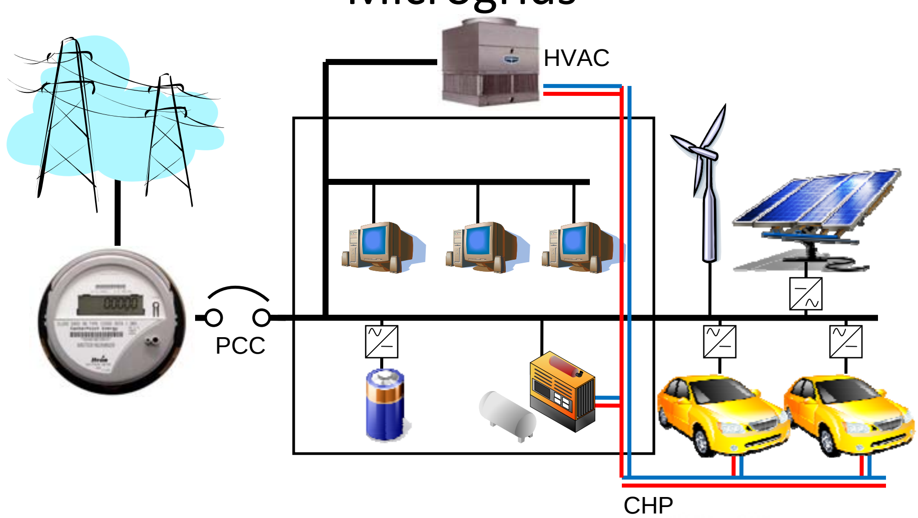
# Community Microgrid Structure

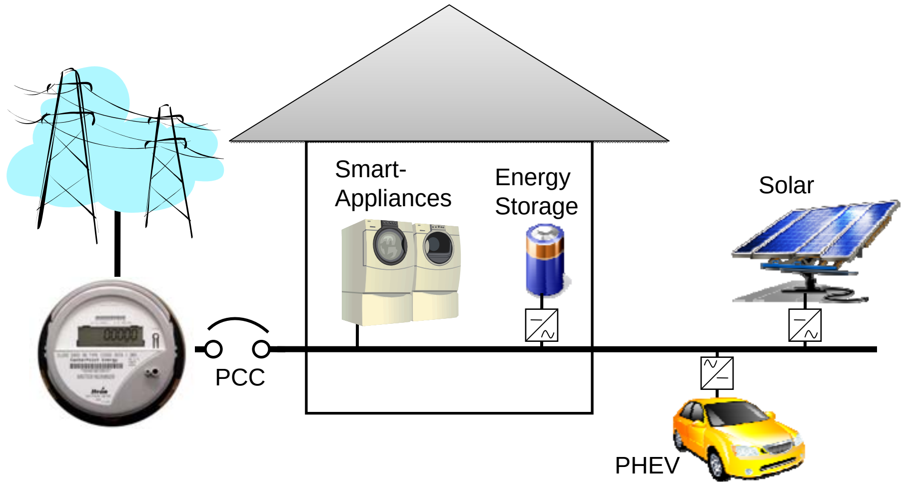





# Corporate Building/Campus Microgrids



# Home Microgrids

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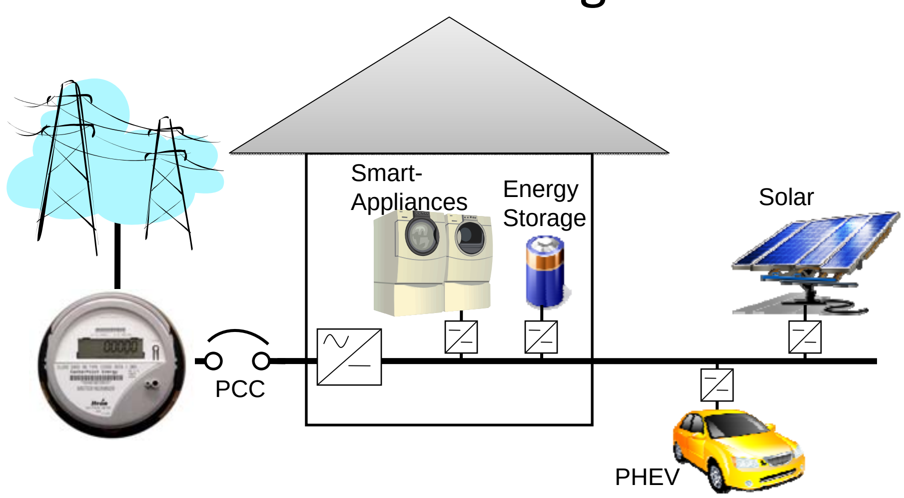
# DC Home Microgrid

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## Major Microgrid Test Sites

- N. America
  - CERTS/AEP – Dolan OH (100 kVA)
  - Northern Power Systems – Waitsfield VT (500 kVA)
  - BC Hydro - Boston Bar BC (10 MVA)
- Asia
  - Shimizu Corp – Tokyo Japan (500 kVA)
  - Sendai Japan (1 MVA)
- Europe
  - Kythnos Island Greece (15 kVA)
  - DEMOTEC - Kassel Germany

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## Standards for Microgrid

- At PCC
- *IEEE-1547:* Standards for Interconnecting Distributed Resources with Electric Power Systems
- *UL-1741*: Inverters, Converters and Controllers for use in Independent Power Systems
- Harmonics
- Anti-Islanding

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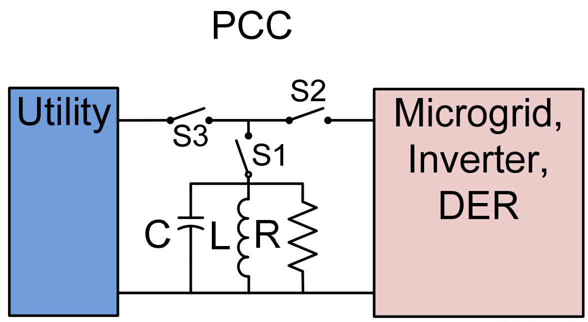
# Anti-Islanding

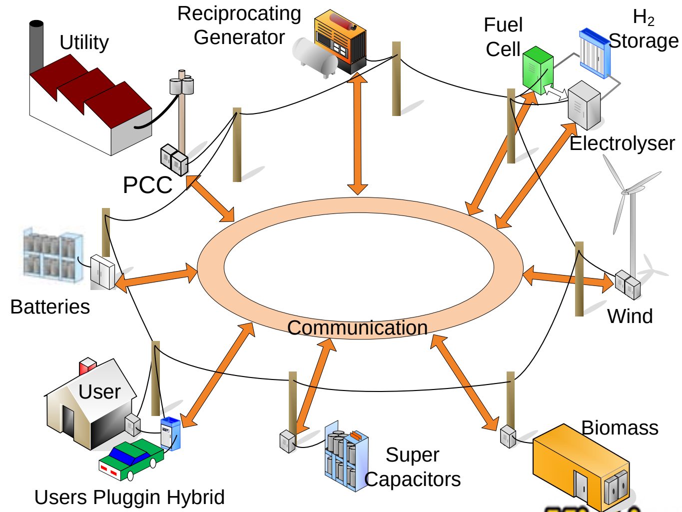
- UL1741 Test Load Circuit at PCC
- Resonant RLC load
- Techniques include phase/frequency drift




# Technical Hurdles: Control and Communications

- Grid connection
  - Sync and re-connect
  - Power Export
- Centralized Control System
  - Global optimization
  - Single point of failure
- Distributed control
  - Modularity/flexibility
  - Local optimization

# Communication/Control Structure

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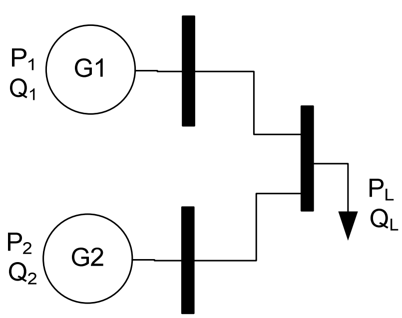
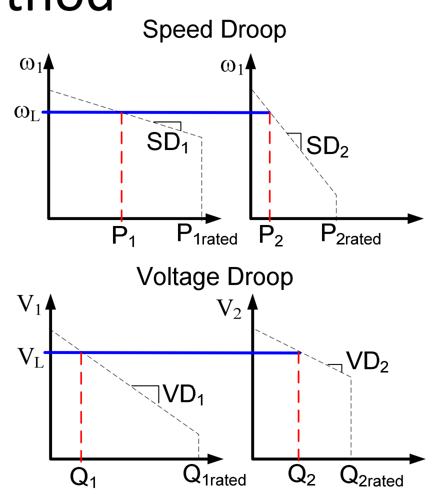
# Droop: Traditional Paralleling Method




$$P_1 + P_2 = P_L$$
$$Q_1 + Q_2 = Q_L$$

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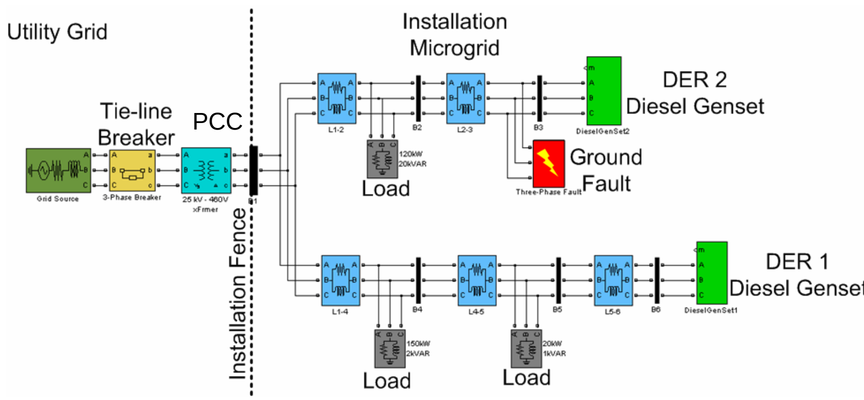
# Microgrid Study

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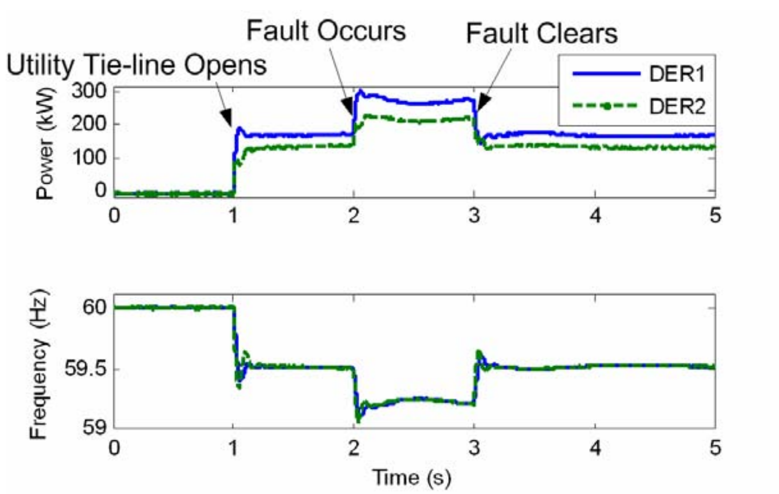
# Droop in a Microgrid

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# Advance Distributed Control

- Every "element" of power system has multiple objectives/commitments
  - Point of Load Converter: Service load power, maintain stability
  - Energy Sources: Supply power, maintain stability
  - Distribution: Route energy most efficiently, maintain stability
- System events/faults can destabilize.
- Action taken by one "elements" influence all other components.
- Game-Theoretic Method: Determine optimal local trajectory given anticipated trajectories of all other components.

# Game-Theoretic Approach to Energy Manament

- Convert components into equivalent impedances.
- The individual dynamics are

$$\dot{e}_i = P_{in} - P_{out} = \frac{(v_i)^2}{r_i} - P_i$$

$$\dot{r}_i = u_i$$

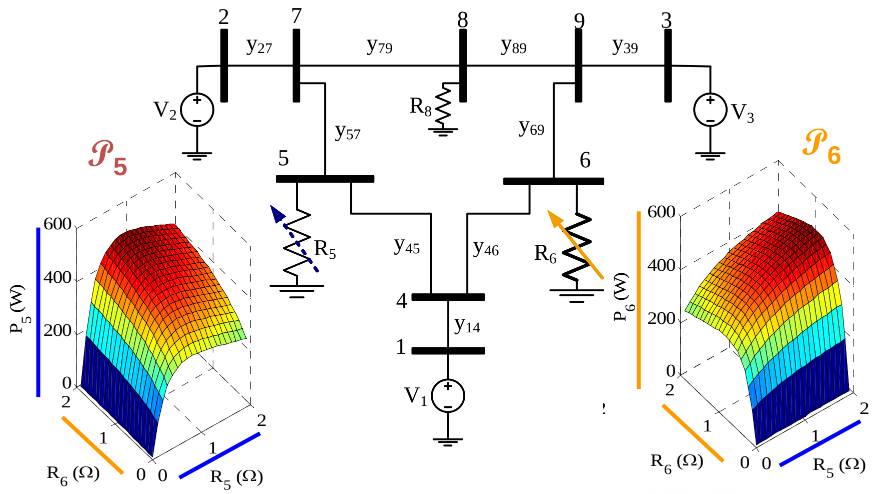
- Individuals interact through the system $\mathbf{I} = \mathbf{YV}$
- Then each component will have an objective

$$J_i(u_i, u_{-i}) = \int f_i(\mathbf{Y}, \mathbf{I}, \mathbf{V}, t, u)dt$$

- For an equilibrium (Nash equilibrium)

$$J_i(u_i^*, u_{-i}^*) \leq J_i(u_i, u_{-i}^*)$$

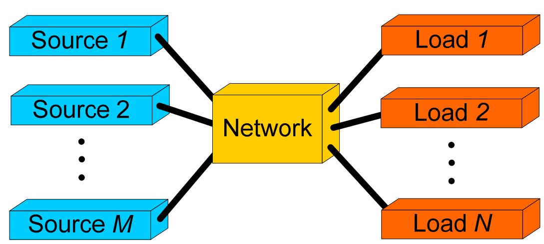
# Example system with 2 “Players”






# Game-Based Energy Management

- Objective Functions
  - Loads
  - Sources
  - Storage
- Game “Rules”
  - Teams
  - Stakelberg (leader / follower )




– “Win” game by maintaining stable, efficient system

# Summary

- "Microgrid" is a broad definition of a small power system
- Benefits include reliability, efficiency, renewables
- Challenges:
  - Control
  - Communications
  - Utility interface at PCC



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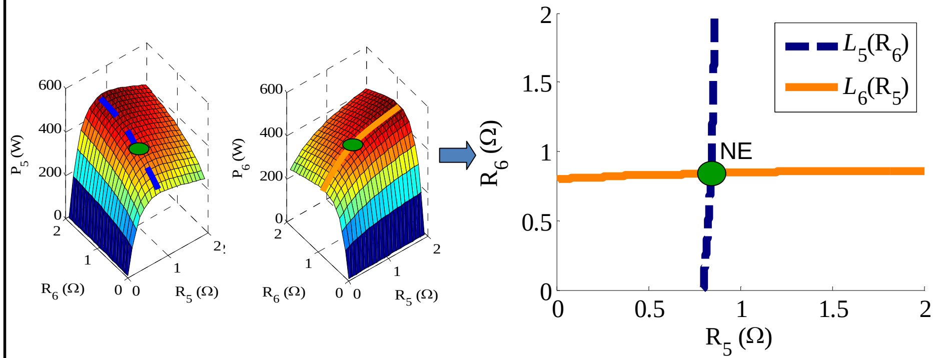
# Solution to Game

- "Solution" is an equilibrium point (Nash) were each player

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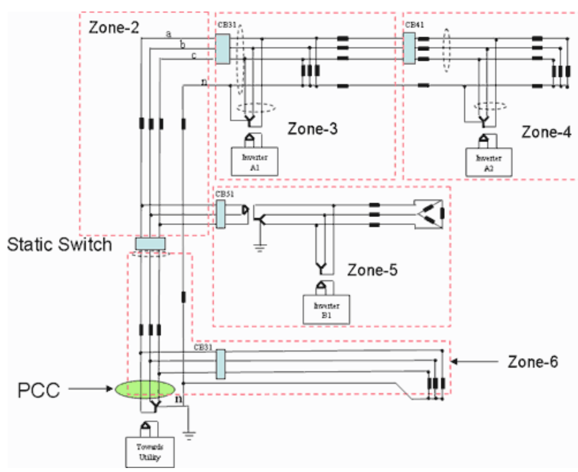
# CERTS Microgrid




Eto, Joseph, Robert Lasseter, Ben Schenkman, John Stevens, Harry Volkommer, Dave Klapp, Ed Linton, Hector Hurtado, Jean Roy, Nancy Jo Lewis. Consortium for Electric Reliability Technology Solutions (CERTS). 2008. CERTS Microgrid Laboratory Test Bed. California Energy Commission, Public Interest Energy Research Program. CEC-500-2008-XXX.

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# Mathematical Coupling of Microgrid Elements