

Smart Grids and Micro-grids

What are they really?

by

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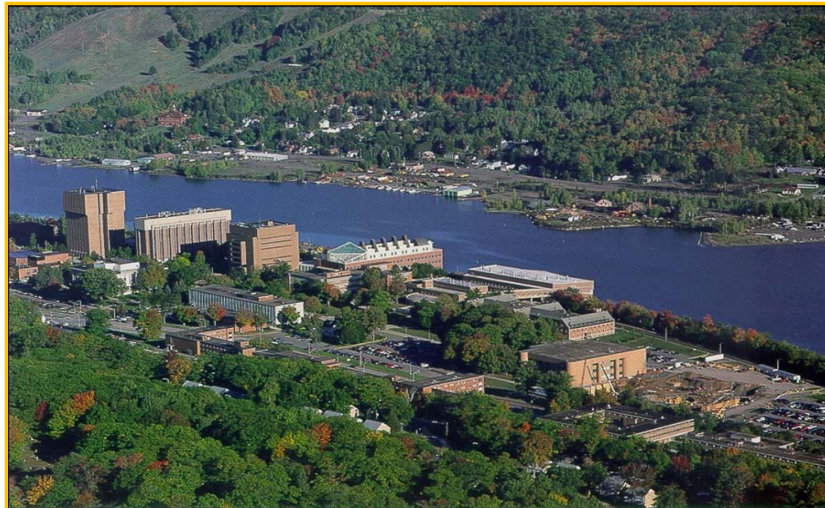
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Quick Overview of EE Power

- 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

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Motivation for this presentation

- Steadily increasing media buzz, little substantive information.
- Only a small subset of possibilities are being discussed. Smart meter \neq 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

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How do you 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.*

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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

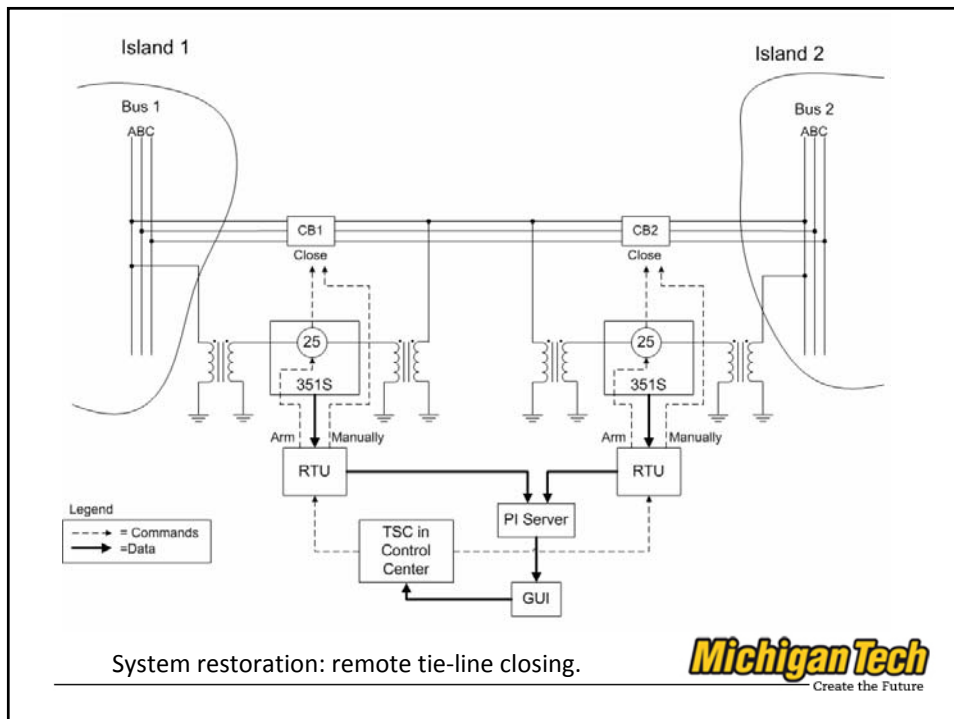
- Hardware
 - Sensors, Embedded processors
 - Integration with other hardware
- Basic Software
 - SCADA, Energy management
 - Vector processors
- Communications
 - Slow (existing SCADA or EMS, more or less)
 - High-speed, high-bandwidth (need to develop)

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Transmission Applications

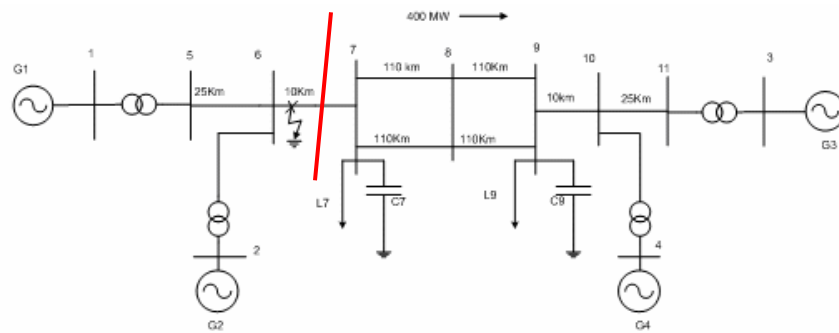
- Phasor measurement units (PMUs) and synchrophasors.
- Grid integration of renewables,
- Advanced metering, operations
- Wide Area: WAM, WAC, WAMPAC
 - Emergency control
 - Voltage Stability: Dynamic VAR control, avoiding voltage collapse
 - Angle Stability: Load shedding, Intelligent system separation

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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.”

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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

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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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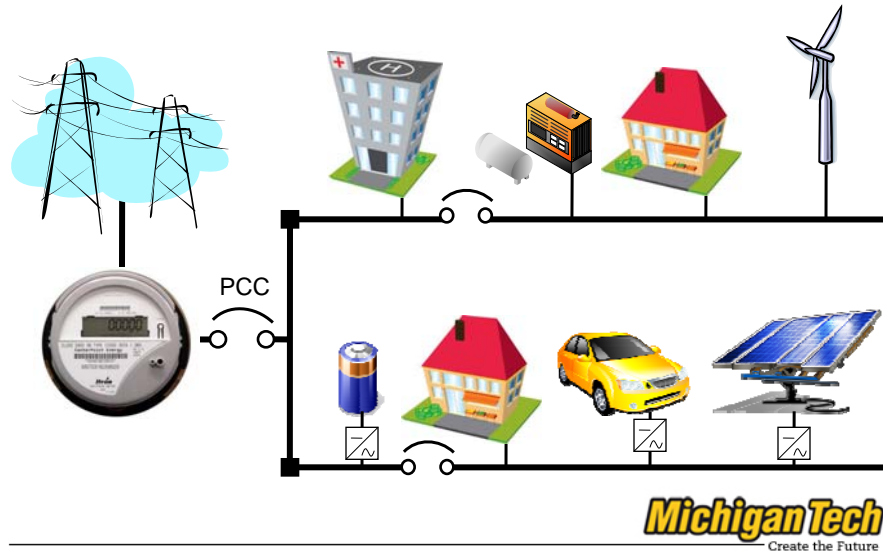
Components of a Microgrid

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

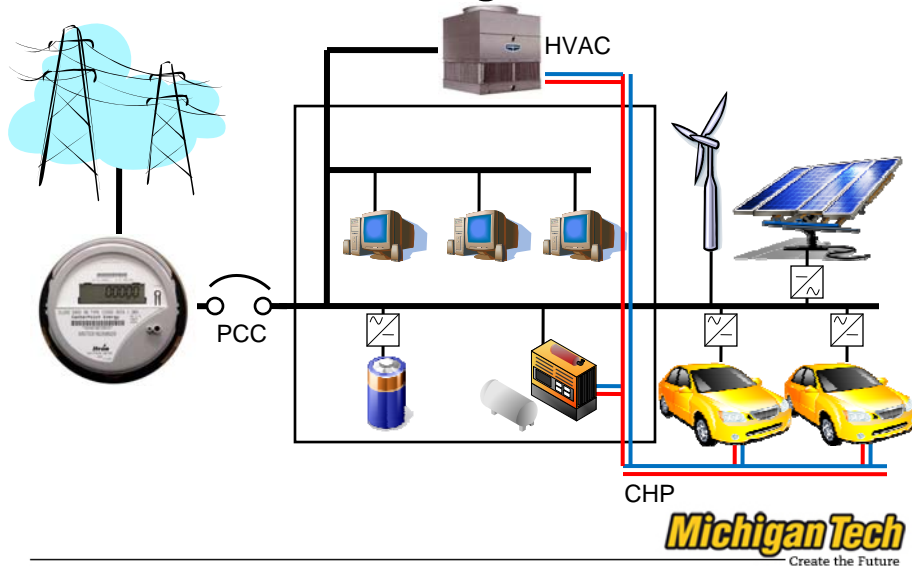
Microgrid Application

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

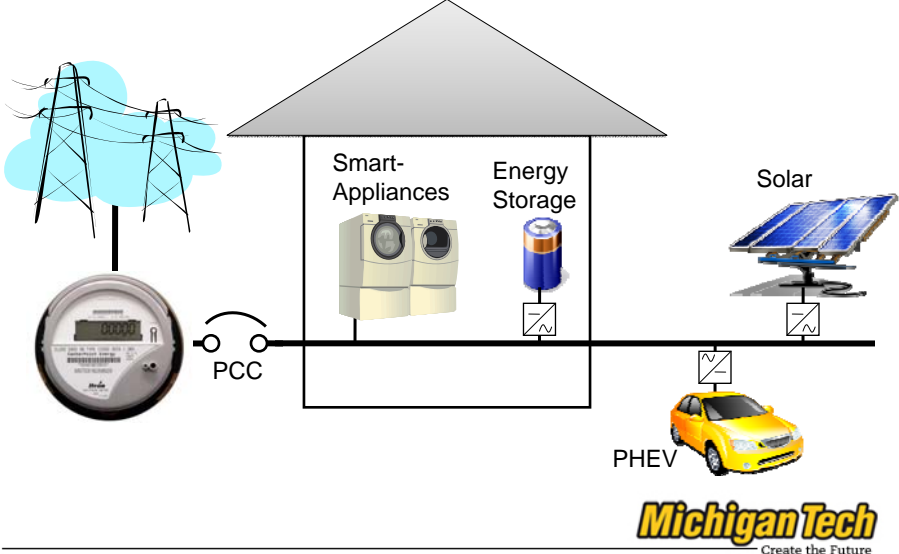
Community Microgrid Structure



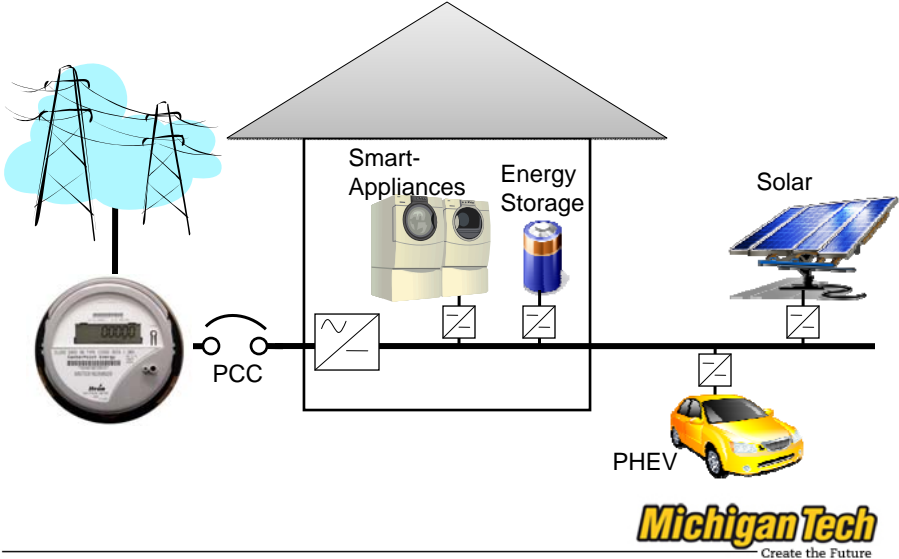
Corporate Building/Campus Microgrids



Home Microgrids



DC Home Microgrid



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



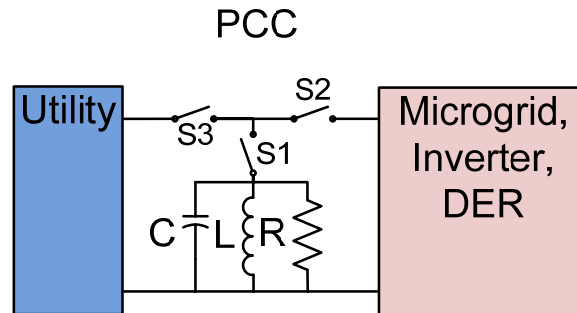
Standards for Microgrid

- 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



Anti-Islanding

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



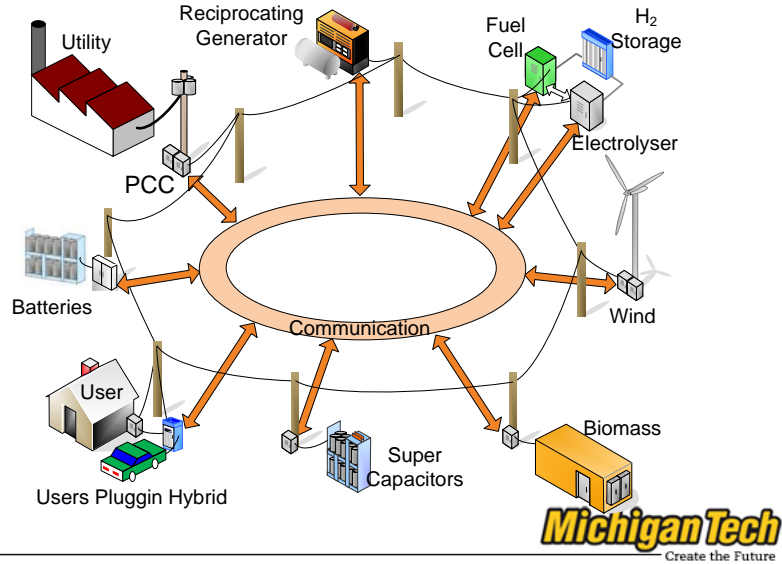
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Technical Hurdles: Control and Communications

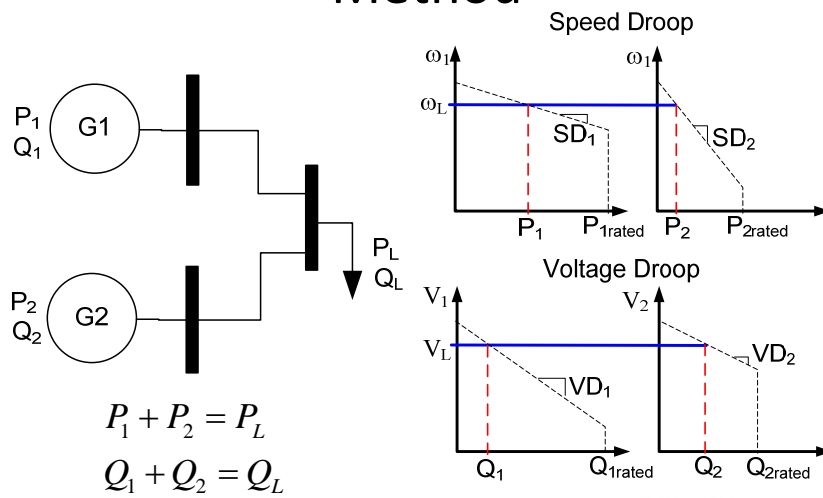
- Grid connection
 - Sync and re-connect
 - Power Export
- Centralized Control System
 - Global optimization
 - Single point of failure
- Distributed control
 - Modularity/flexibility
 - Local optimization

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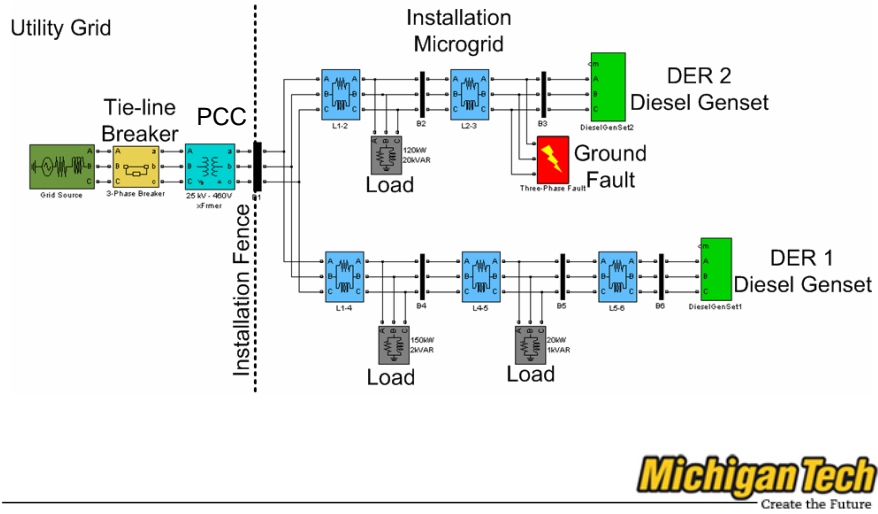
Communication/Control Structure



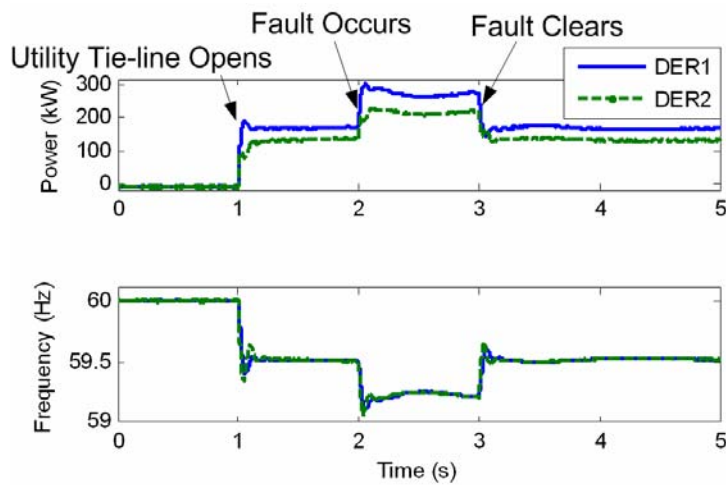
Droop: Traditional Paralleling Method



Microgrid Study



Droop in a Microgrid



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.

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Game-Theoretic Approach to Energy Managment

- 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

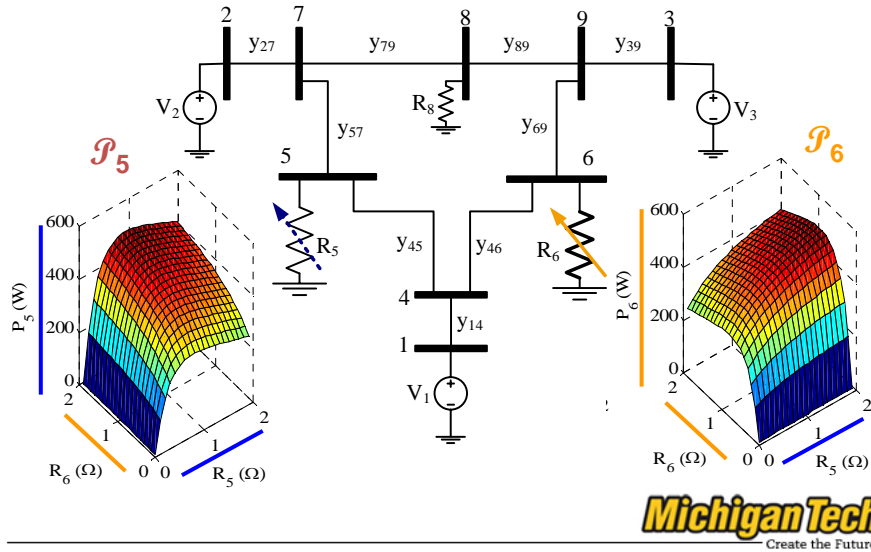
$$J_i(u_i, u_{-i}) = \int f_i(\mathbf{Y}, \mathbf{I}, \mathbf{V}, t, u) dt$$

- For an equilibrium (Nash equilibrium)

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

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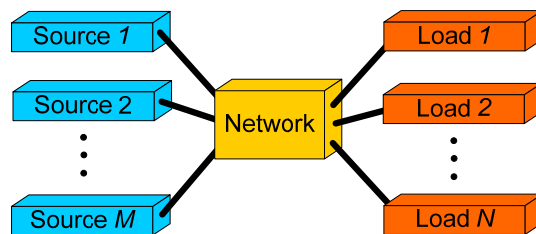
Example system with 2 “Players”



Game-Based Energy Management

- Objective Functions

- Loads
- Sources
- Storage



- Game “Rules”

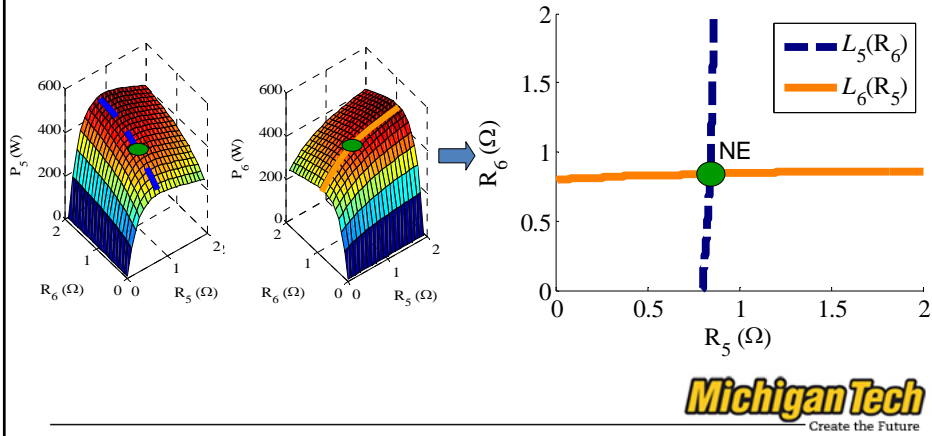
- Teams
- Stakelberg (leader / follower)
- “Win” game by maintaining stable, efficient system

Summary

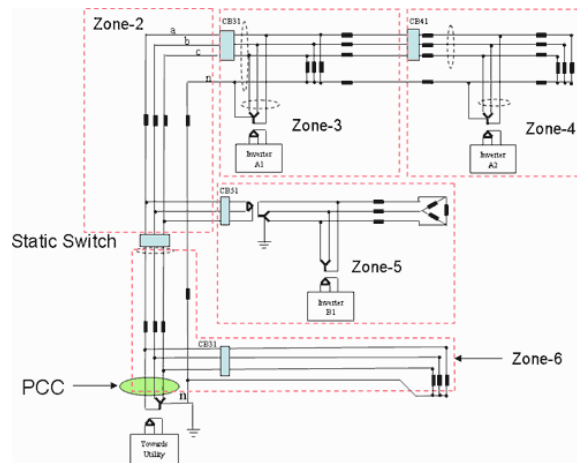
- “Microgrid” is a broad definition of a small power system
- Benefits include reliability, efficiency, renewables
- Challenges:
 - Control
 - Communications
 - Utility interface at PCC

Solution to Game

- “Solution” is an equilibrium point (Nash) where each player



CERTS Microgrid



Eto, Joseph, Robert Lasseter, Ben Schenkman, John Stevens, Harry Volkammer, 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.

Mathematical Coupling of Microgrid Elements

