Smart Grids and Cloud Computing

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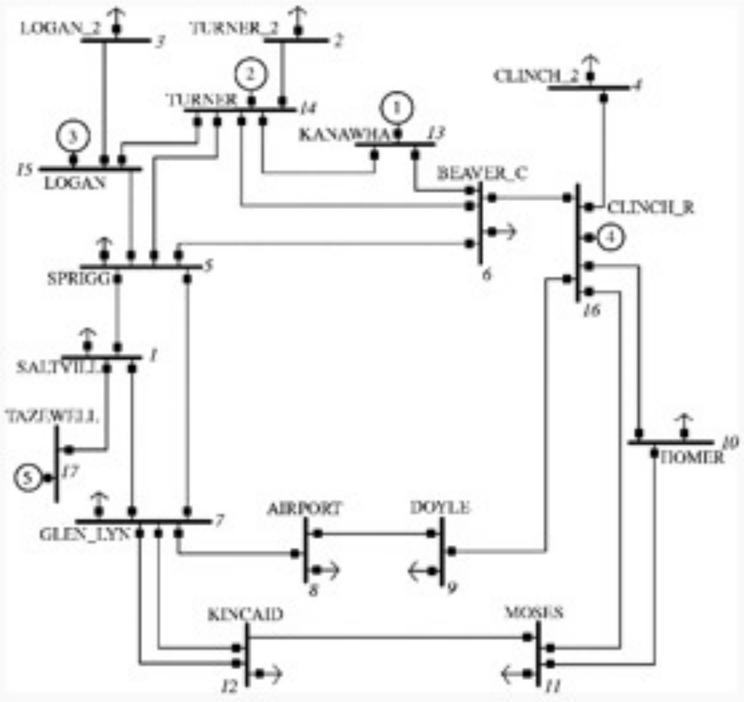
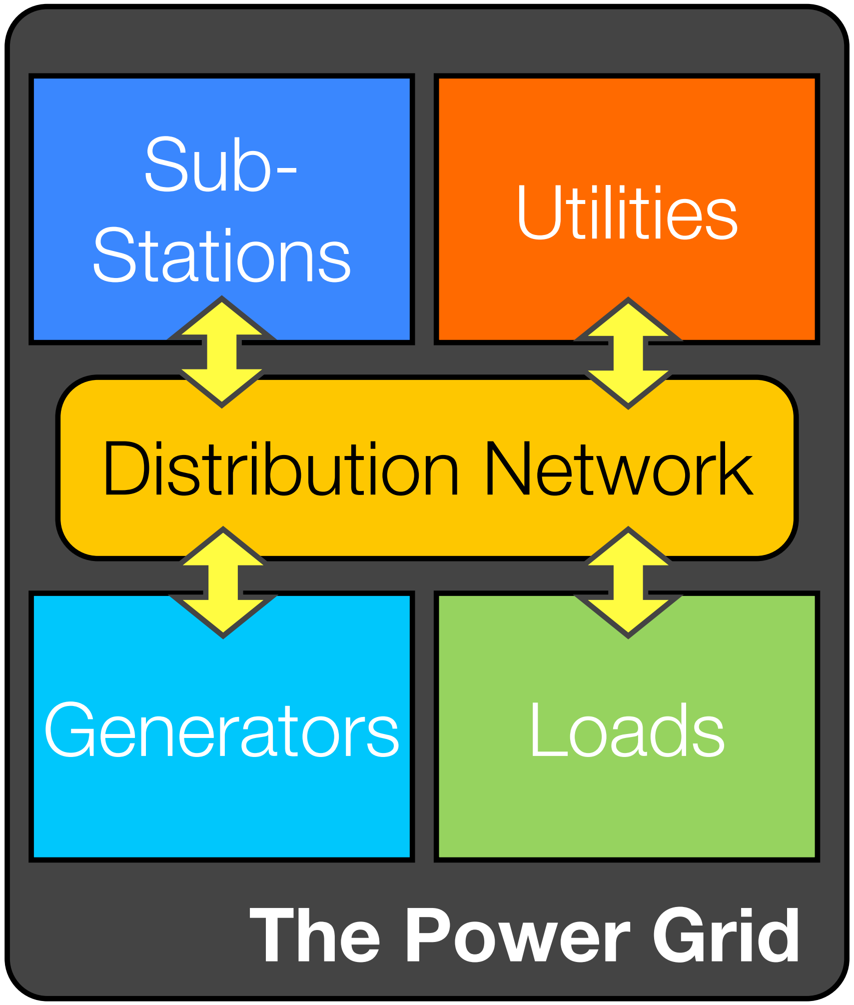
Power Grids

- Power Grids are formed mainly from generators, networks and loads
- Utilities will often control the power grid, and sub-stations will also be built to step voltages and ensure transmission





Sub-Stations

Utilities

Distribution Network

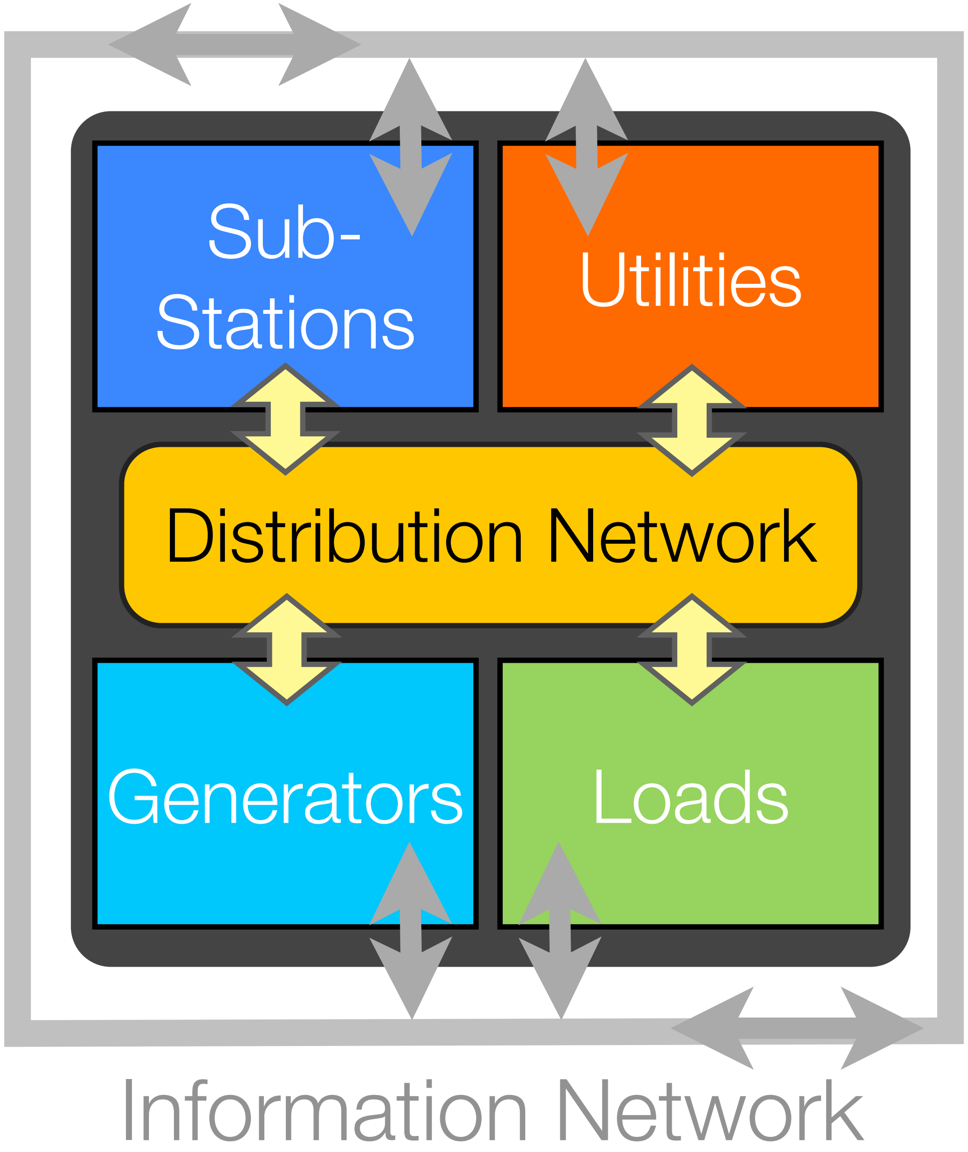
Generators

Loads

The Power Grid

Smart Grids

- Term dates back to at least 2005
    - "Toward A Smart Grid", by S. Massoud Amin and Bruce F. Wollenberg
- Many definitions, but all focus on idea of data flow and information management central to the power grid



Sub-Stations

Utilities

Distribution Network

Generators

Loads

Information Network

What is the Smart Grid?

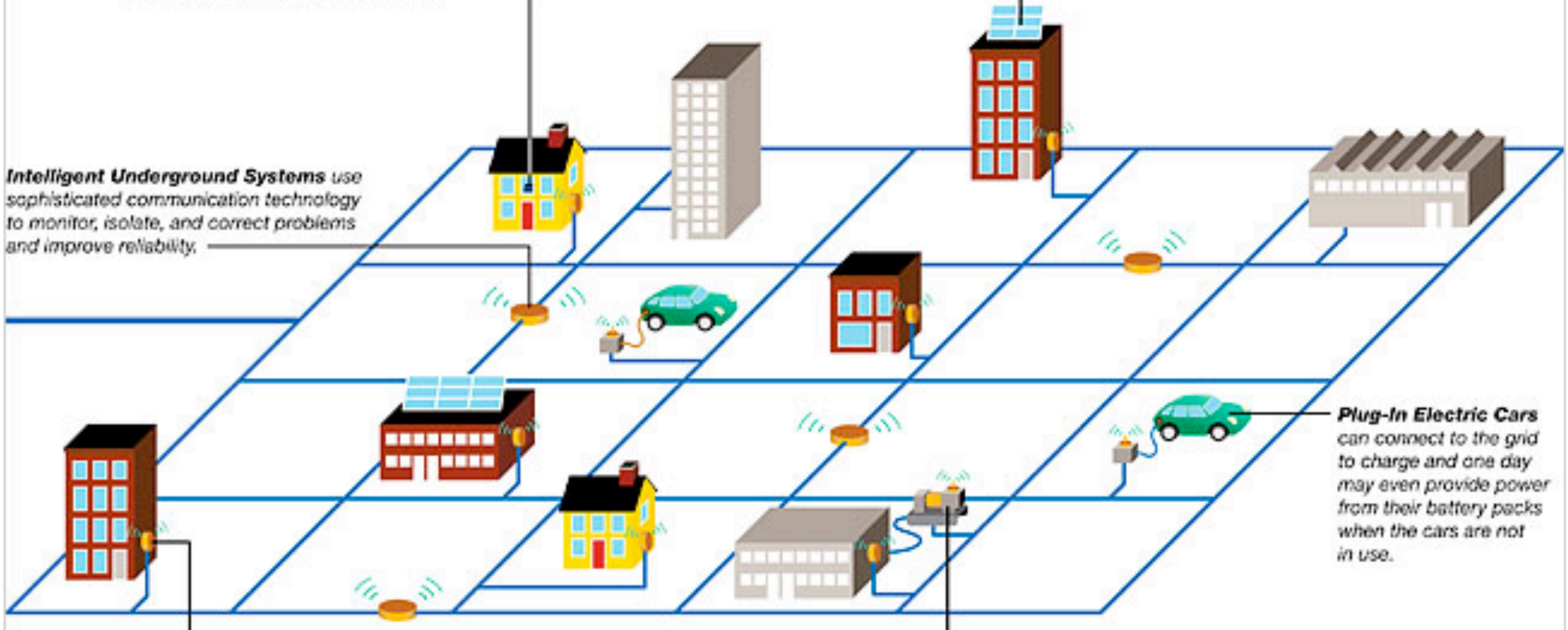
1. Optimize asset utilization and operating efficiency.
2. Accommodate all generation and storage options.
3. Provide power quality for the range of needs in a digital economy.
4. Anticipate and respond to system disturbances in a self-healing manner.
5. Operate resiliently against physical and cyber attacks and natural disasters.
6. Enable active participation by consumers.
7. Enable new products, services, and markets.

DOE 2008

conEdison

Smart Grid

Smart grid puts information and communication technology into electricity generation, delivery, and consumption, making systems cleaner, safer, and more reliable and efficient.



Smart Building Technology *including web portals and in-home displays will eventually allow customers to track their energy use and give them the tools to change their energy-using habits.*

Greener Energy Sources *are more readily integrated into the smart distribution grid.*

Intelligent Underground Systems *use sophisticated communication technology to monitor, isolate, and correct problems and improve reliability.*

Plug-In Electric Cars *can connect to the grid to charge and one day may even provide power from their battery packs when the cars are not in use.*

Smart Meters *gather information about customers' energy use so customers can use electricity more efficiently, and the meters may enable the utility to identify system problems.*

Customer Energy Generators *enhance system reliability.*

Why the Smart Grid?

1,638 billion kWh of energy is lost in the US grid annually

655 billion kWh lost in the distribution system alone

Reduce by 10%

Saves

$5.7 Billion

Cuts

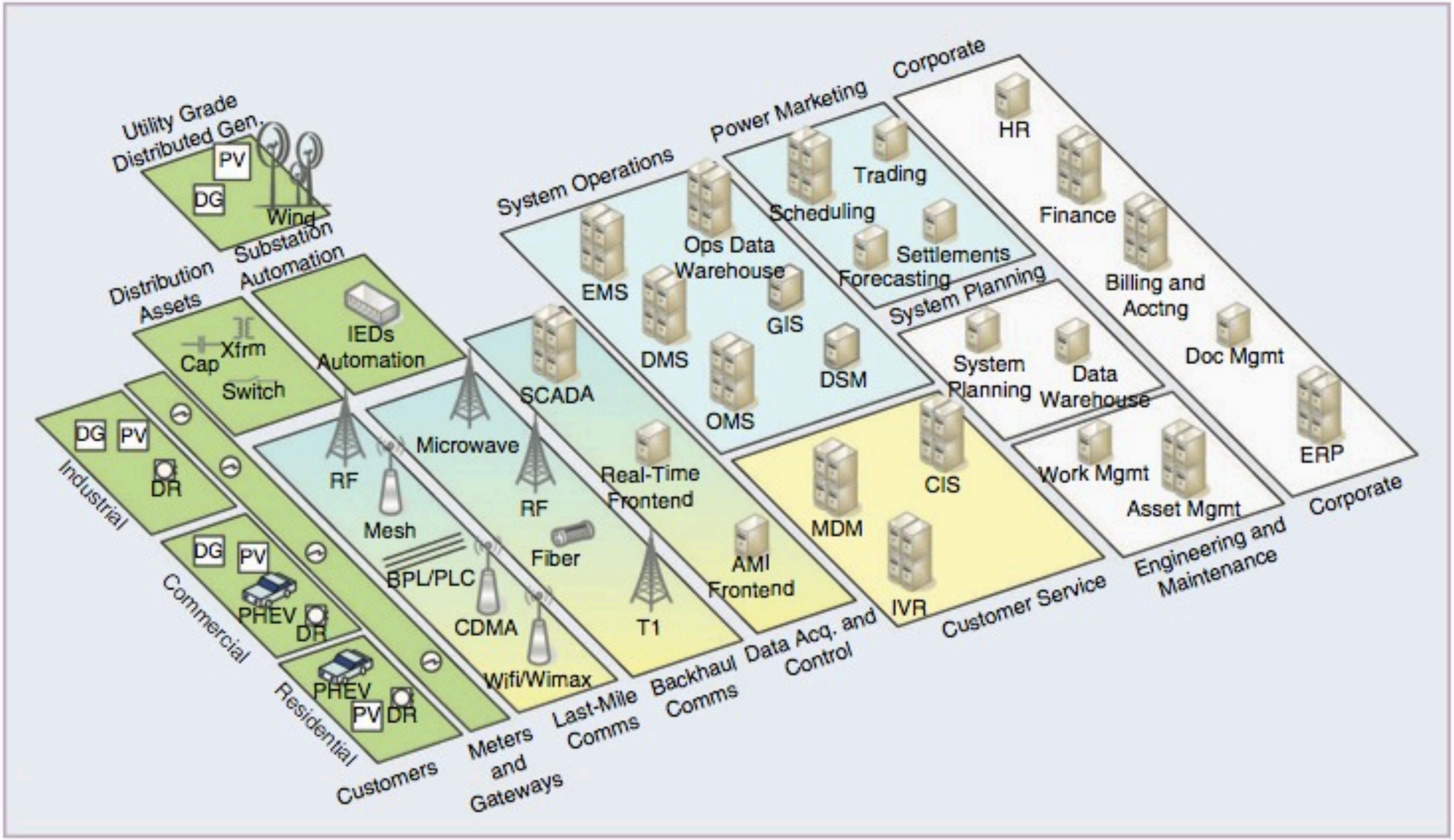
42 million tons of CO2

(2006) (ABB)

Smart Grid Technologies

Sensor/Acutator	Automated Switches, Smart Metering, Distribution Network Distributed Sensors
Communication	Wireless and Wired Networking, Control centers, Inter ISO communication
Power Flow Control	HVDC, Volt/Var Optimization, Flow Controls
Decision Intelligence	Microgrid control, Wide-area monitoring, system events and alerts, end-user management, Supervisory control and data acquisition systems (SCADA)

Smart Grid Systems



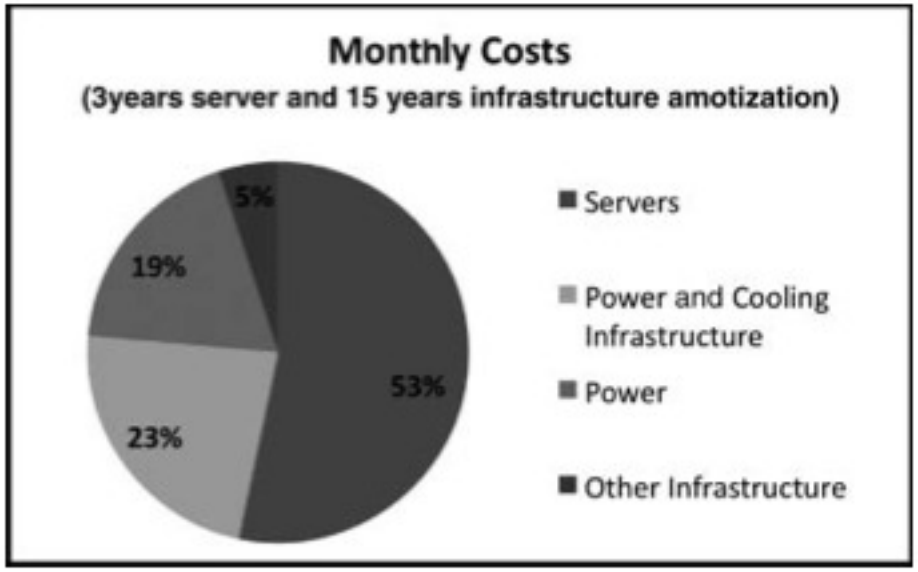
(Ipakchi) ©2009 IEEE

Smart Grid: Research Applications

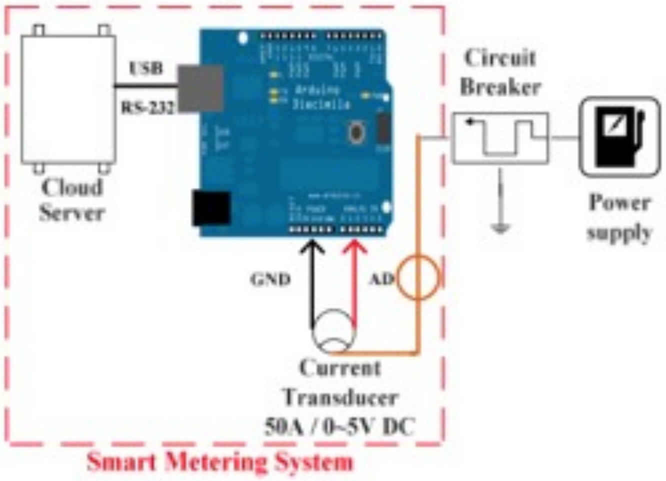
- Optimization of Power Flow in a Non-Linear Framework
- Effects of Local Storage and Local Generation
- Effects of Gradual Addition of Smart Grid Technologies
- Optimal Market Pricing Strategies with the Introduction of Real Time Pricing
- Market Clearing Strategies with Renewable Energy
- Security in Control Systems (SCADA)

Focus: How to Make Data Centers Smart?

- What makes Data Centers expensive?
  - Designed with Resistance to Maximum Possible Transient Peaks
  - Designed with “unlimited power concept”
  - Heating and cooling not considered by software/electrical engineers
- Possible Solution:
  Addition of Smart Monitoring (Tu, et. al) to read the power flow on each server



Berl, et. al

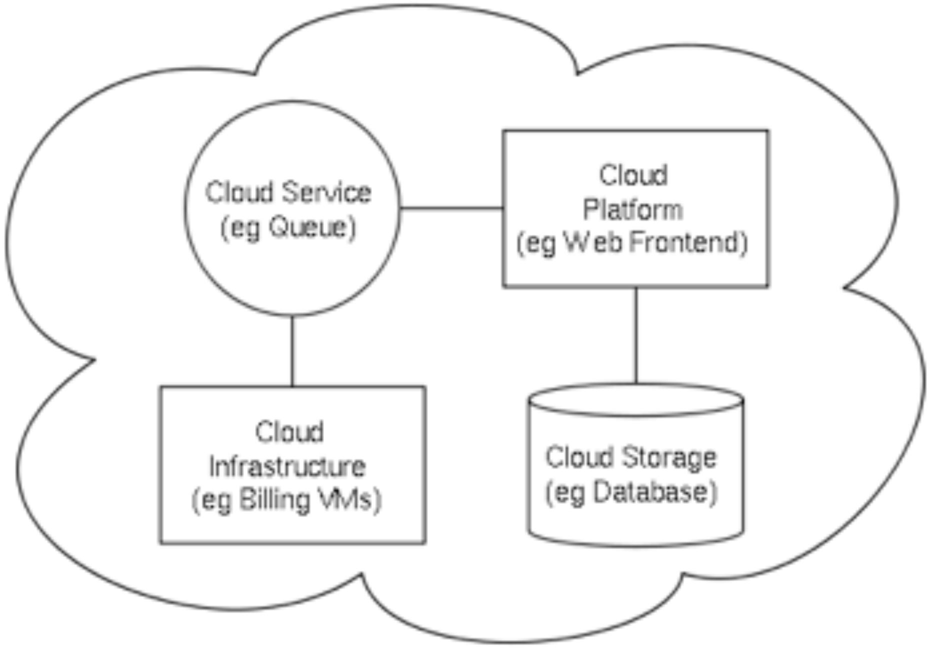


Tu, et. al

Focus: Smart Grids and Data Centers

- Cloud Computing
  - Computing, software and data services that can be used by end users without knowledge of physical location or configuration of the systems
- Cloud computing uses data centers around the world to provide services
  - **Amazon**: (Ashburn, Virginia; Dallas/Fort Worth; Los Angeles; Miami; Newark, New Jersey; Palo Alto, California; Seattle; St. Louis; Amsterdam; Dublin; Frankfurt; London; Hong Kong; Singapore; Tokyo)

"Where Amazon's Data Centers Are Located" www.datacenterknowledge.com/ November 18th, 2008 : Rich Miller



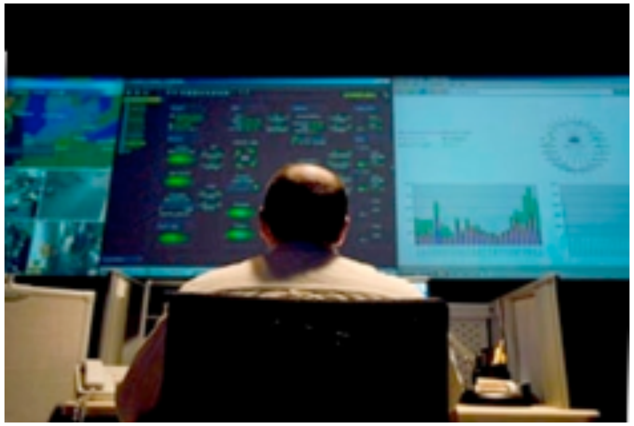
Windows Azure
Microsoft's Cloud Services Platform

amazon webservices™

cloudservers™

Focus: Smart Grids and Data Centers

- Problem: Current Cloud Computing does not take into consideration power constraints
- Solution: Geographical routing of requests to data centers where power is available, cheaper, easier to balance
- Objective: Route requests to data centers to best balance the power distribution network (Mohsenian-Rad, A.; Leon-Garcia, A.;)



Focus: Smart Grids and Data Centers

- Model the power supply and data centers as buses
- Each bus may have generators and loads (data centers, background load)
- Buses are connected by limited branches
- Each bus is modeled as (DC-Equivalent Power Flow Equations)

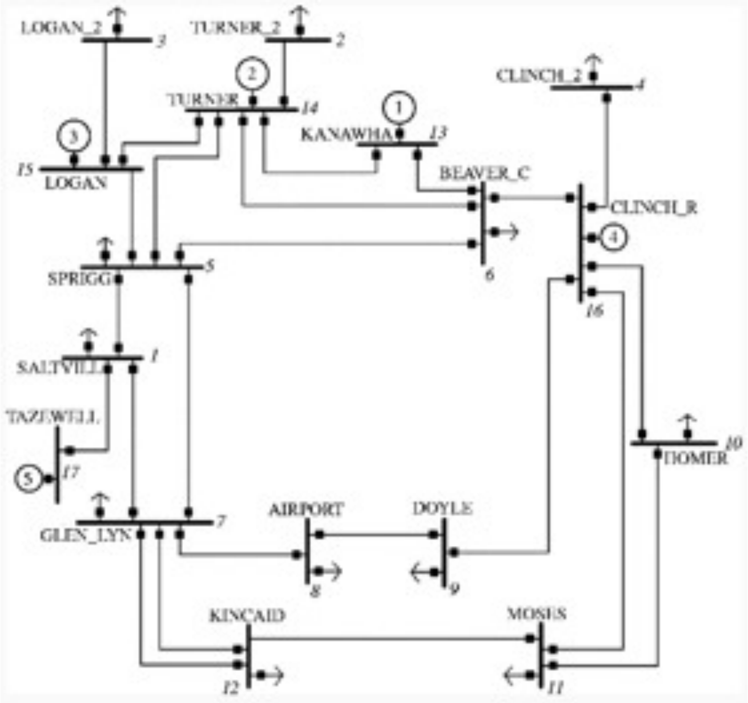
$$P_i = \sum_{j=1, j \neq i} B_{ij} \left(\theta_i - \theta_j\right), \qquad \forall\, i \in \mathcal{N},$$

- Each branch can be described as

$$P_{ij} = B_{ij} \left(\theta_i - \theta_j\right).$$

- Therefore, the system can be described as

$$\boldsymbol{P} = \boldsymbol{P}^{\text{Background}} + \boldsymbol{P}^{\text{DataCenter}}$$



Focus: Smart Grids and Data Centers

- Set of Buses that Feed a Data Center

$$\mathcal{S} \subseteq \mathcal{N}$$

- Set of Buses that Feed a User

$$\mathcal{U} \subseteq \mathcal{N}$$

- Service Requests at U Routed To S

$$\lambda_{us}$$

- Therefore, all requests must be met

$$\sum_{s \in \mathcal{S}} \lambda_{us} = L_u, \qquad \forall\, u \in \mathcal{U}$$

$$\gamma_s \triangleq \left(\sum_{u \in \mathcal{U}} \lambda_{su} \right) / \left(m_s\, \mu \right), \qquad \forall\, s \in \mathcal{S}.$$

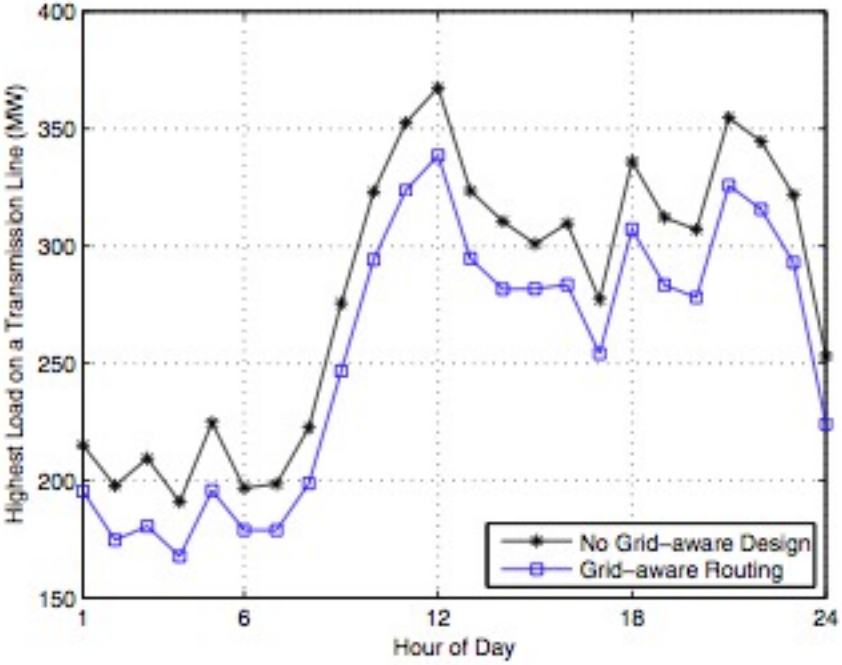
- Average Server Utilization at s
- Then,

$$\begin{aligned} P_s^{\text{DataCenter}} \triangleq\ & m_s \left(P_{idle} + (E_{usage} - 1) \times P_{peak} \right) \\ & + m_s \left(P_{peak} - P_{idle} \right) \times \gamma_s + \epsilon, \end{aligned}$$

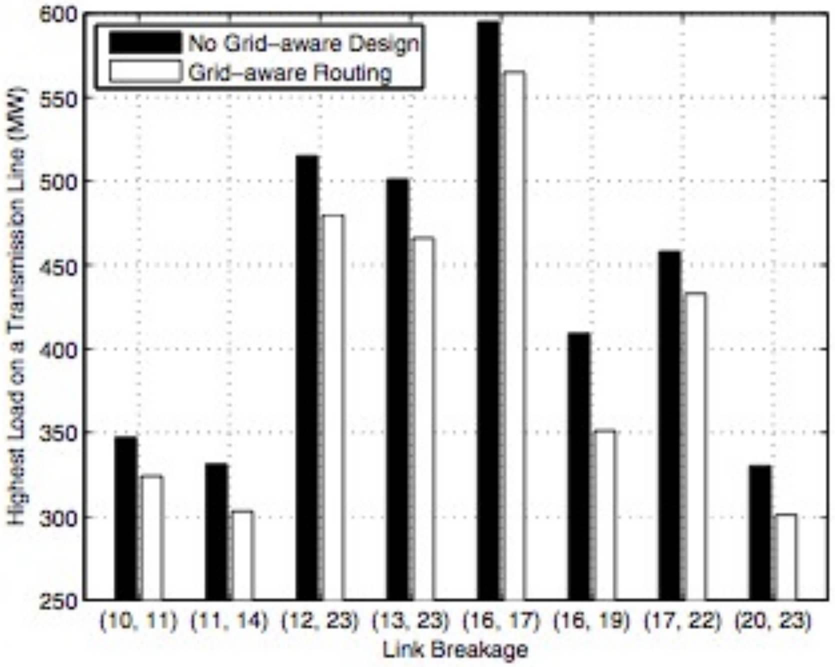
- For each branch, one wants to keep the ratio with respect to maximum low

$$\begin{array}{ll} \underset{\lambda}{\textbf{minimize}} & \max\limits_{(i,j)}\ P_{ij} / P_{ij}^{\max} \\ \textbf{subject to} & \text{Eqs. } (1) - (12). \end{array}$$

Focus: Smart Grids and Data Centers



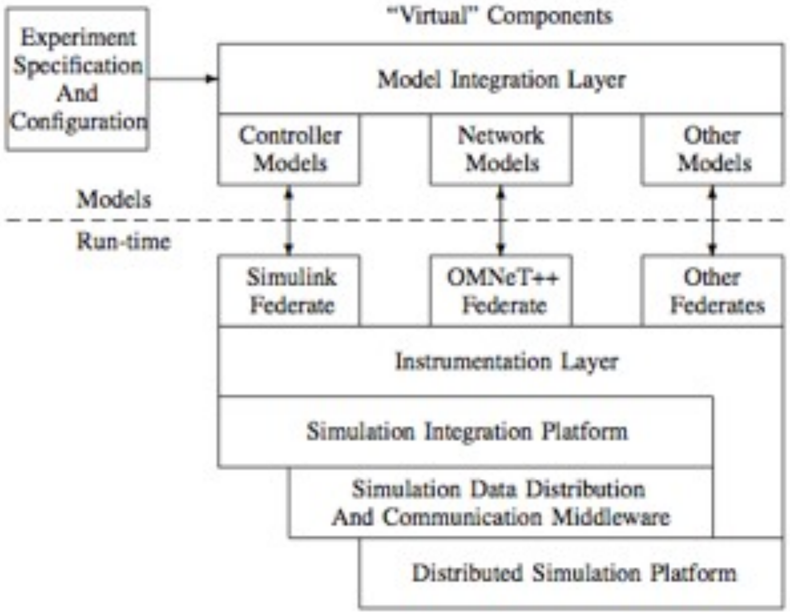
Effect of Grid-Aware Routing on Maximum Transmission



Effect of Grid-Aware Routing on Link Breakage

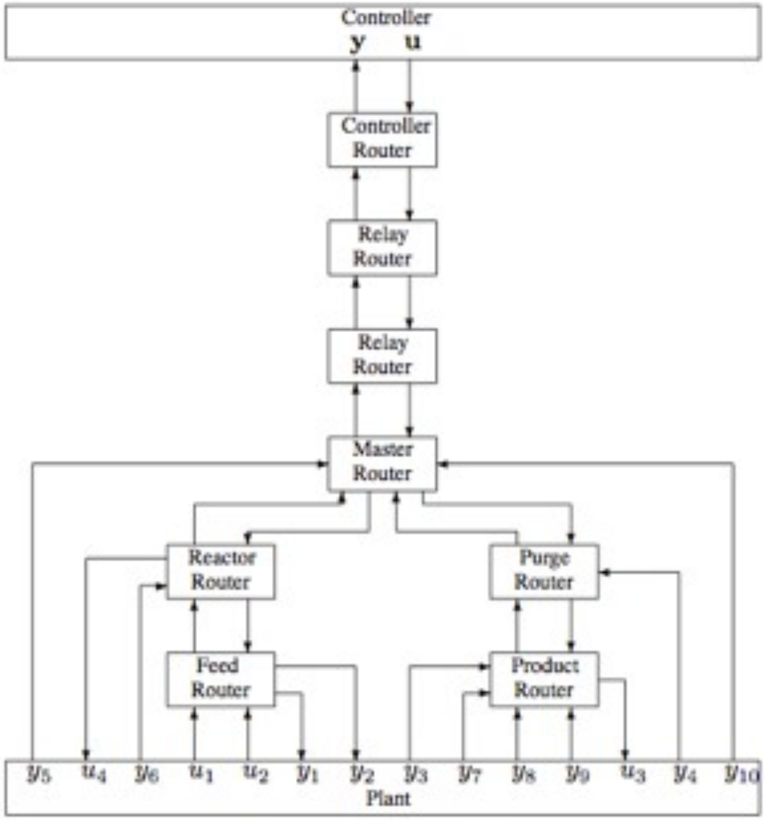
Focus: Controllable SCADAs and the Risk of Attack

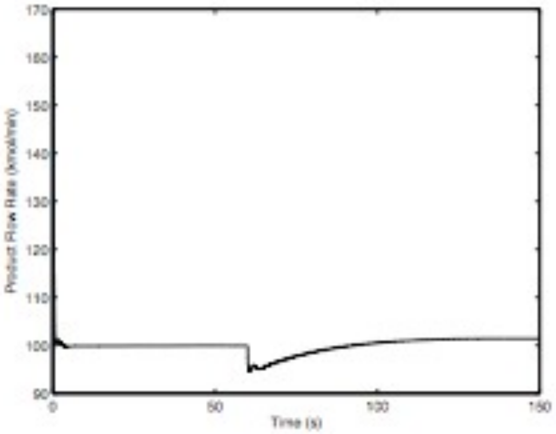
- Problem: With more intelligent control systems, this opens them up to the risk of attack. What happens when a control system on a generator is attacked?
- Solution: Model the generator, and then model the effect of losing control
  (Rohan Chabukswar, Bruno Sinopoli, Gabor Karsai, Annarita Giani, Himanshu Neema, Andrew Davis.)
- Used the Tennessee Eastman Control Challenge Problem



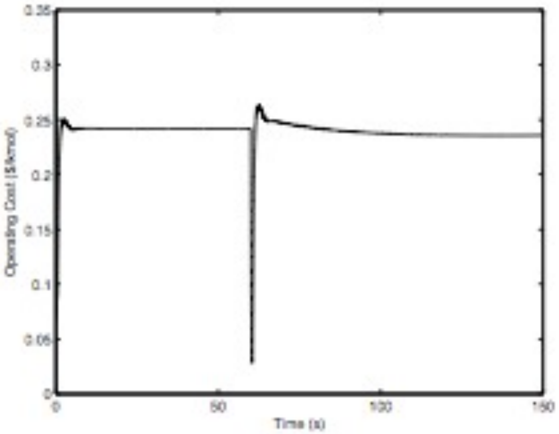
Focus: Controllable SCADAs and the Risk of Attack

- Conclusion: The effect of total communications disruption was modelable, but attacks on the feed router and product router were harder to simulate and estimate





(b) Product Flow Rate



(c) Operating Cost

Cited Works

1. “The Smart Grid: An Introduction” US Department Of Energy Office of Electricity Delivery and Energy Reliability. 2008. http://www.oe.energy.gov/SmartGridIntroduction.htm;
2. KAZEMZADEH, HORMOZ; OHRN, MARINA. “Smartness in Control” *ABB Review*. ABB. 2010
3. A Ipakchi, F Albuyeh, “Grid of the future” Power and Energy Magazine, IEEE, 2009
4. Liu, Whe “Analytics and information integration for smart grid applications” Power and Energy Society General Meeting, 2010
5. Mohsenian-Rad, A.; Leon-Garcia, A.; , "Coordination of Cloud Computing and Smart Power Grids," Smart Grid Communications (SmartGridComm), 2010 First IEEE International Conference on , vol., no., pp.368-372, 4-6 Oct. 2010 doi: 10.1109/SMARTGRID.2010.5622069 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5622069&isnumber=5621989
6. Parthasarathy Ranganathan. 2010. Recipe for efficiency: principles of power-aware computing. Commun. ACM 53, 4 (April 2010), 60-67. DOI=10.1145/1721654.1721673 http://doi.acm.org/10.1145/1721654.1721673
7. Singh, T.; Vara, P.K.; , "Smart Metering the Clouds," Enabling Technologies: Infrastructures for Collaborative Enterprises, 2009. WETICE '09. 18th IEEE International Workshops on , vol., no., pp.66-71, June 29 2009-July 1 2009 doi: 10.1109/WETICE.2009.49 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5159216&isnumber=5159183
8. Berl, Andreas and Gelenbe, Erol and Di Girolamo, Marco and Giuliani, Giovanni and De Meer, Hermann and Dang, Minh Quan and Pentikousis, Kostas; , “Energy-Efficient Cloud Computing” The Computer Journal. vol 53 no 7 URL: http://comjnl.oxfordjournals.org/content/53/7/1045.full.pdf+html
9. Rohan Chabukswar, Bruno Sinopoli, Gabor Karsai, Annarita Giani, Himanshu Neema, Andrew Davis. "Simulation of Network Attacks on SCADA Systems". First Workshop on Secure Control Systems, Cyber Physical Systems Week 2010, April, 2010.