Smart Grid

Sorting the reality from the hype

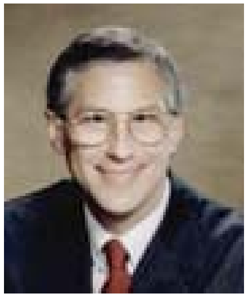
A briefing by Carnegie Mellon University Faculty

Carnegie Mellon

Today's speakers:

Ed Schlesinger, Head of the Department of Electrical and Computer Engineering (ECE) will talk about finally bringing the electronic revolution, that has transformed so many other fields, to the electric power system.

Granger Morgan, Head of the Department of Engineering and public Policy (EPP), and a Professor in ECE, will lay out a road map of the many different meanings of the phrase "smart grid."



Jay Apt, Executive Director of Carnegie Mellon's Electricity Industry Center, and a Professor in EPP and the Tepper School of Business, will discuss how smart grid technology can be used to facilitate the use of large amounts of variable and intermittent forms of generation such as wind.

Marija Ilic, Professor in ECE and EPP, will talk about how to use advanced smart grid control technology to better monitor and control efficiently the nation's high voltage transmission system.

Today's speakers…(Cont.)

Gabriela Hug, Professor in ECE will talk about how FACTS technology together with smart control can move more power through existing transmission lines.

Lester Lave, Professor in Tepper and EPP will talk about how smart meters and control of appliances can save large amounts of energy.

Bruno Sinopoli, Professor in ECE, will talk about the cyber vulnerabilities that could come with smart gird and strategies that could be used to make the grid more secure.

We will conclude the session with a round table discussion that explores several key policy issues and responds to questions from the audience.

Bringing the electronic revolution to the power system (finally!)

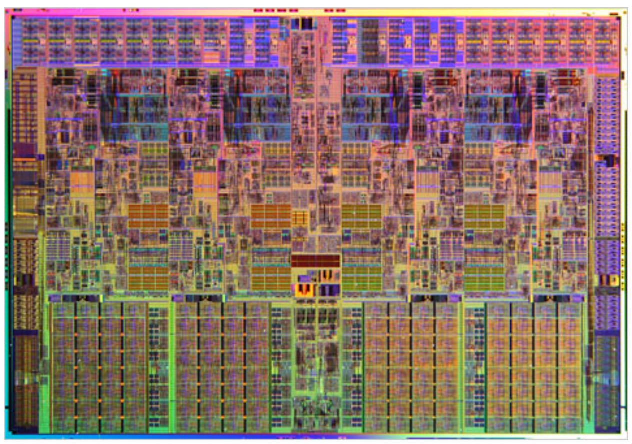
Electronic technology has fundamentally altered the way we live;

- Communications
- Commerce
- Entertainment
- …

What has been the key to these changes?

Information Technology

- Integrated circuits have developed in a manner that provides ever growing information handling power at ever decreasing cost
- Key to the development of this technology and its wide adoption:
  - the ability to model and design these systems
  - the associated development of software systems



+

```
    int SelectedAlgorithm, i, AnonymityLevel;
    FILE AutoMessage;
    char* Key;

fprintf(stdout,'%s\n','What algorithm to use?');
fprintf(stdout,'%s\n','1. RSA');
fprintf(stdout,'%s\n','2. EL GAMAL');
fprintf(stdout,'%s\n','3. DES');
scanf('%d', &SelectedAlgorithm);
if(SelectedAlgorithm!=1    &&    SelectedAlgorithm!=2    &&
SelectedAlgorithm!=3)
    return CORRUPTED;

if (SelectedAlgorithm==3) {
        exec sql select Key into :Key
        from key_table
        where algorithm = :SelectedAlgorithm
        and User = :UserID;
    }
    else {
        exec sql select Key into :Key
        from public_key_table
        where algorithm = :SelectedAlgorithm
        and User = :Recipient;
    }

for (i=0; SelectedFilesList[i]!='\0'; i++) {
        AttachmentsList[i]=Encrypt(SelectedFilesList[i],
        SelectedAlgorithm, Key);
}

fprintf(stdout,'%s\n','What level to invoke?');
scanf('%d', &AnonymityLevel);
```

Application to Power Systems

- The creation of "smart grids" is the application of information technology to the power system while coupling this with an understanding of the business and regulatory environment
- Critical to the creation of "smart grids" is;
  - development of models of the power system
  - development of command and control software
  - incorporation of security, communications, and safety systems
  - BEFORE hardware is deployed!

Creation of "Smart Grids"

- Clear definition of what "Smart Grids" means
- Deep understanding of the complexity of the power system
- Ability to not simply introduce/develop technology but to understand the effects of changes
- Ensure, up front, security, efficiency, reliability, and integration with business/regulatory environment

The many meanings of "smart grid"

While the phrase smart grid is widely used, it means very different things to different people.

Some of the things that get talked about are relatively inexpensive and can go a long way toward solving key problems.

Others will likely be very expensive, and at this stage may better be left to the realm of research.

The Many Means of "Smart Grid"

A Briefing Note from the Department of Engineering and Public Policy Carnegie Mellon University

July 2009

The many meanings of "Smart Grid"

M. Granger Morgan, Jay Apt, Lester B. Lave, Marija D. Ilic, Marvin Sirbu, and Jon M. Peha

America seems to have decided that a "smart grid" is what we need to solve the problems of our electric power system. But, what exactly *is* a "smart grid"?

The answer is that it is many different things. Some of the things that get talked about are relatively inexpensive and can go a long way toward solving key problems. Others will likely be very expensive, and at this stage may better be left to the realm of research.

At the level of the customer:

- Meters that can be read automatically, without sending a meter reader out once a month. This can be done in several different ways: with a signal that is sent back to the transformer or substation over the power line (power line carrier) and then on to the utility in some other way; by a radio link in the local neighborhood; or by a van that drives around the neighborhood and asks each meter to give an automatic readout, via radio links. Systems like this are already widely deployed by many power companies, and generally pay for themselves through reduced meter reading costs.
- Time-of-day and time-of-use meters (there is a difference). Most customers in the USA today pay a flat average rate for electricity. Some industrial and commercial customers pay rates that reflect the real cost of generating power, that can be cheap at night and expensive at times of peak demand when every generating unit is pressed into service, including old and inefficient ones. Time-of-day meters basically contain a clock and charge different rates at different fixed times of the day (e.g. "on-peak" and "off-peak"). These meters bill at a higher price at a time-of-day when the demand for power is typically high, regardless of actual demand on that particular day. A few utilities have had time-of-day systems in place for both residential and commercial customers for over 50 years.

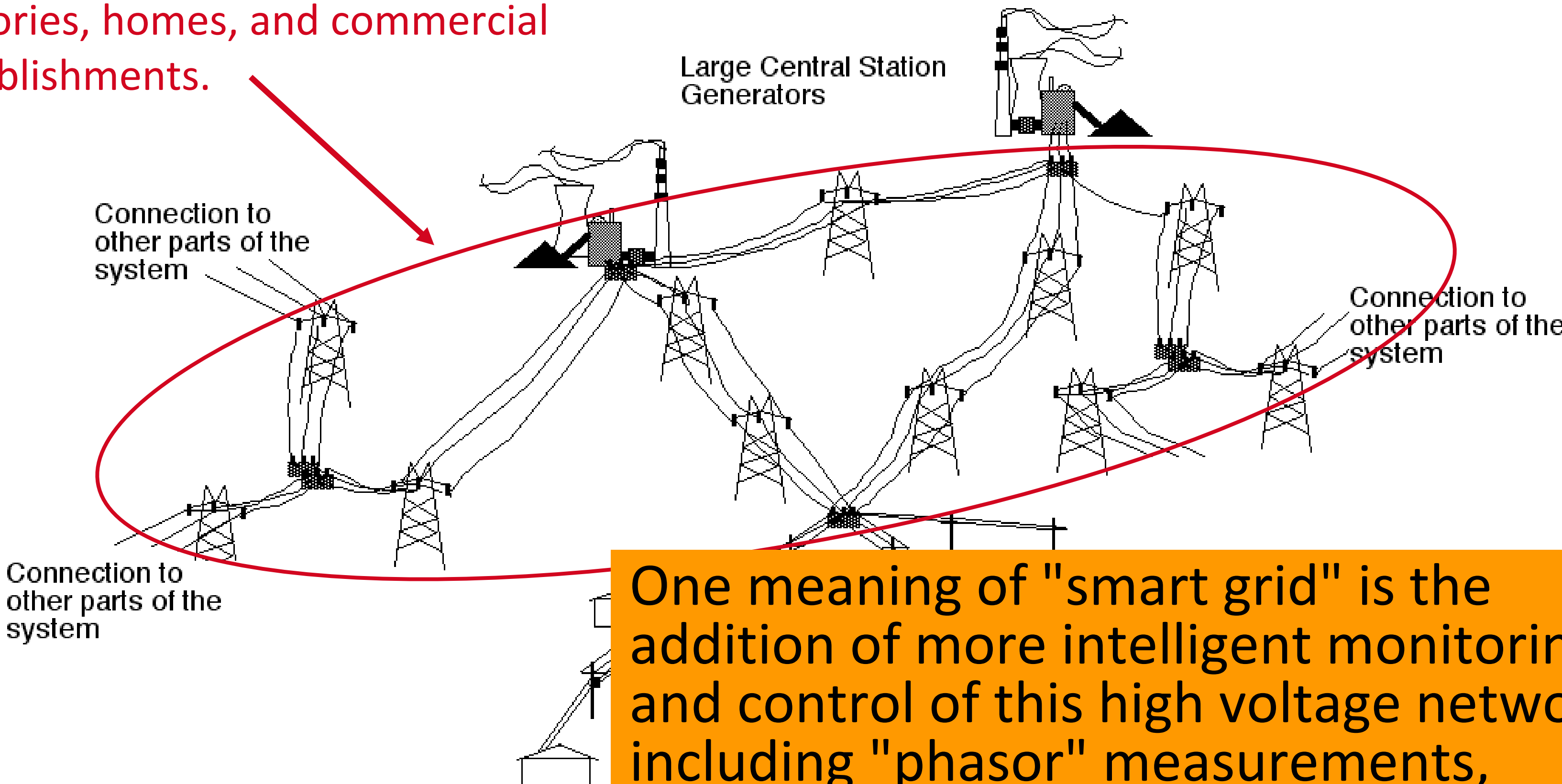
  In contrast, "time-of-use" or "real-time" meters receive signals from the power company and switch to higher or lower rates as the actual cost of providing power to a customer goes up and down.

  Both technologies are intended to reduce peak loads so that less generation and transmission capacity is needed. Time-of-use meters can do this more effectively and can respond in real time to unusual stresses on the system. Research done in Carnegie Mellon's Electricity Industry Center has shown that in most systems, only about 20% of the larger and more flexible customers need to be switched from conventional meters to real-time meters, in order for everyone to get as much as 80% of the benefits that would be achieved if all customers were on real-time meters. This suggests that today the

At Carnegie Mellon, research on the electricity system is being conducted by the campus-wide Electricity Industry Center (www.cmu.edu/electricity) and by the Electric Energy Systems Group in Electrical and Computer Engineering (www.eesg.ece.cmu.edu/). Research on information system security is conducted in CyLab (www.cylab.cmu.edu).

Structure of the power system

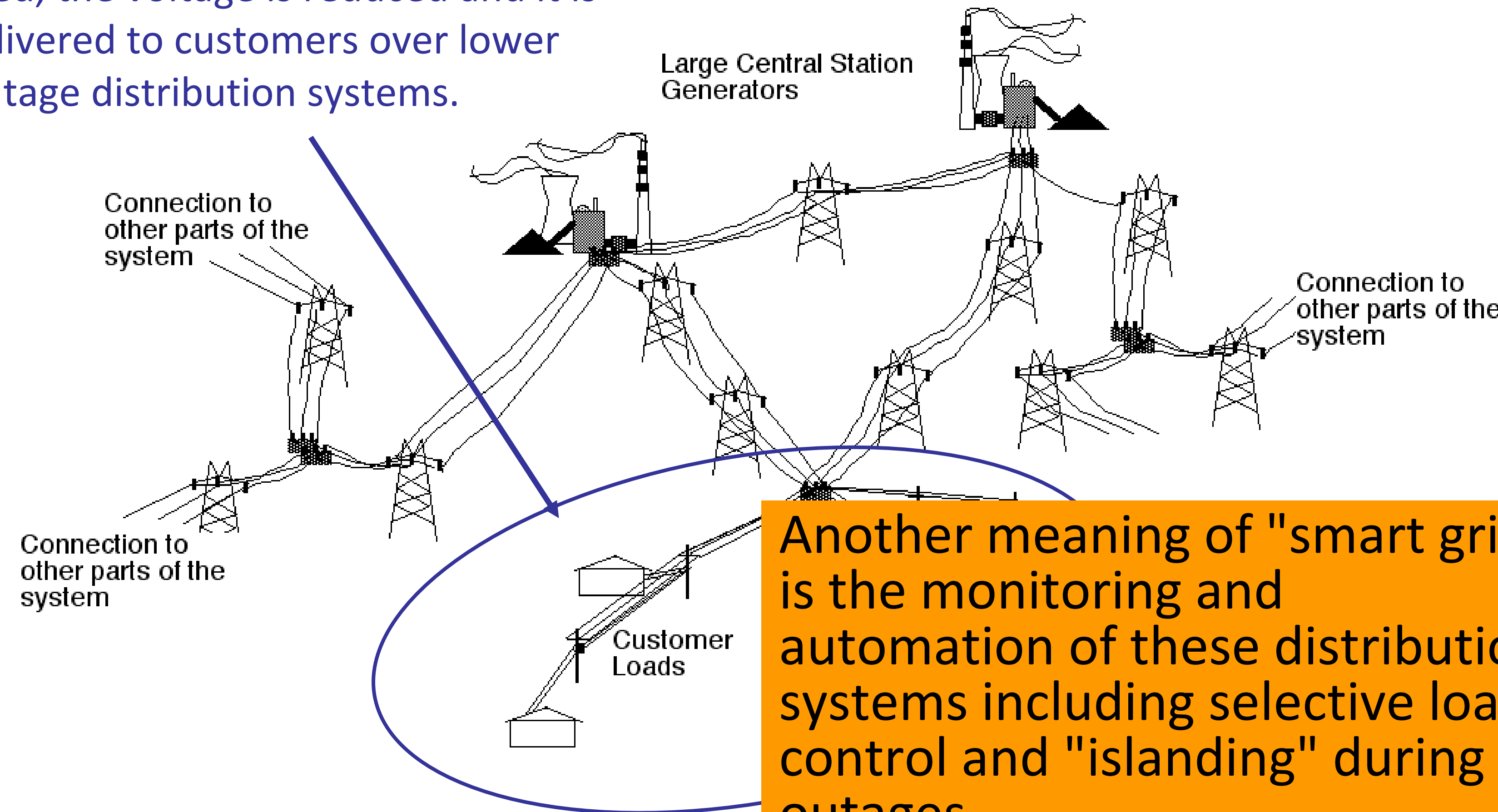
The high voltage transmission system moves power from central generators out to where it is needed by factories, homes, and commercial establishments.



One meaning of "smart grid" is the addition of more intelligent monitoring and control of this high voltage network including "phasor" measurements, distributed control, FACTS etc..

Structure of the power system

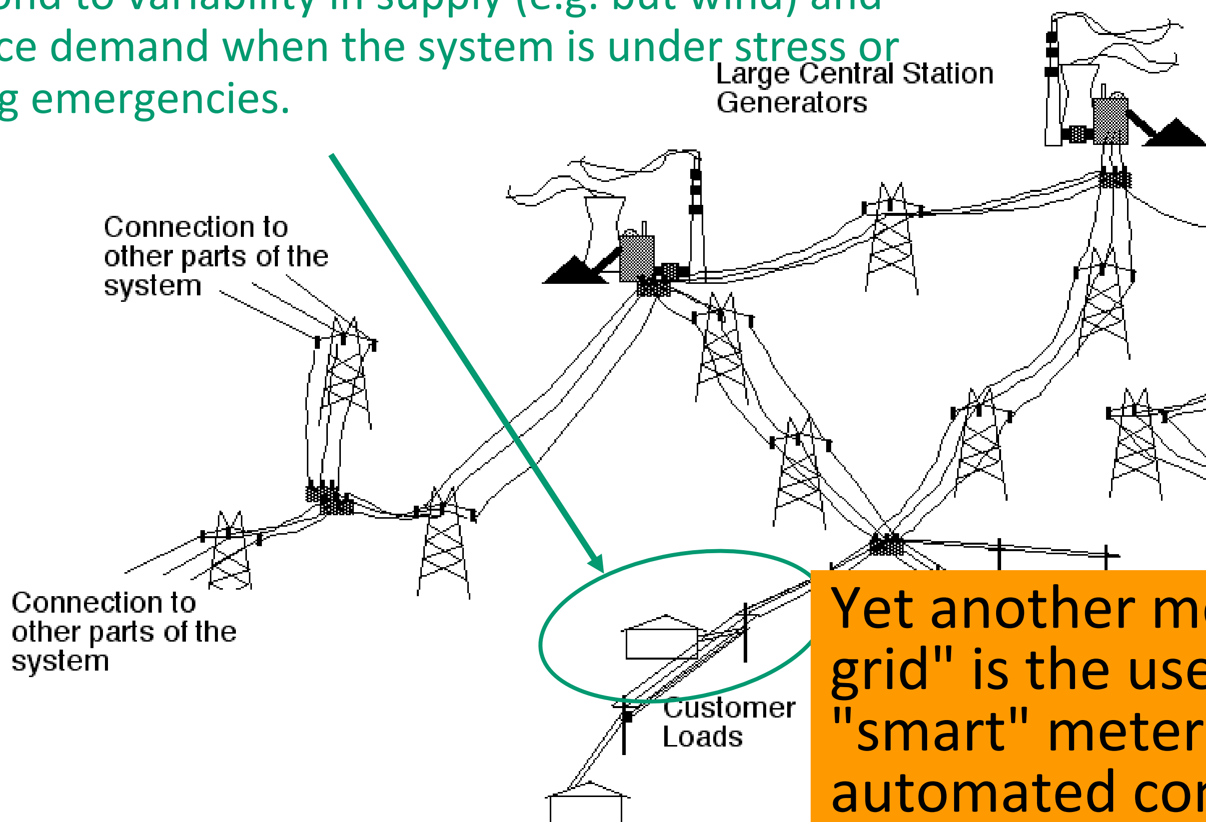
Once power the power has been delivered to the region where it will be used, the voltage is reduced and it is delivered to customers over lower voltage distribution systems.



Another meaning of "smart grid" is the monitoring and automation of these distribution systems including selective load control and "islanding" during outages.

Structure of the power system

By adding real time meters and automated load control at customer's premises electricity can be used more efficiently and load can be adjusted to respond to variability in supply (e.g. but wind) and reduce demand when the system is under stress or facing emergencies.



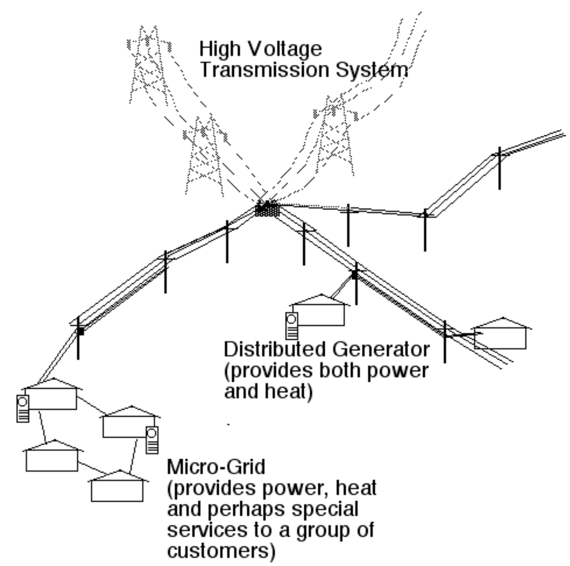
Yet another meaning of "smart grid" is the use of real-time "smart" meters and the automated control of traditional and newer loads such as PEVs.

Smart grid raises several regulatory and policy issues

Examples:

- Distributed generation with combined heat and power, operated as parts of micro-grids can double the efficiency with which we use energy and increase supply reliability.

  Smart grid can facilitate this technology. However because of state laws granting "exclusive service territories" to legacy utilities, micro-grids are not legal in most states. This needs to be changed.



Regulatory and policy issues

Examples:

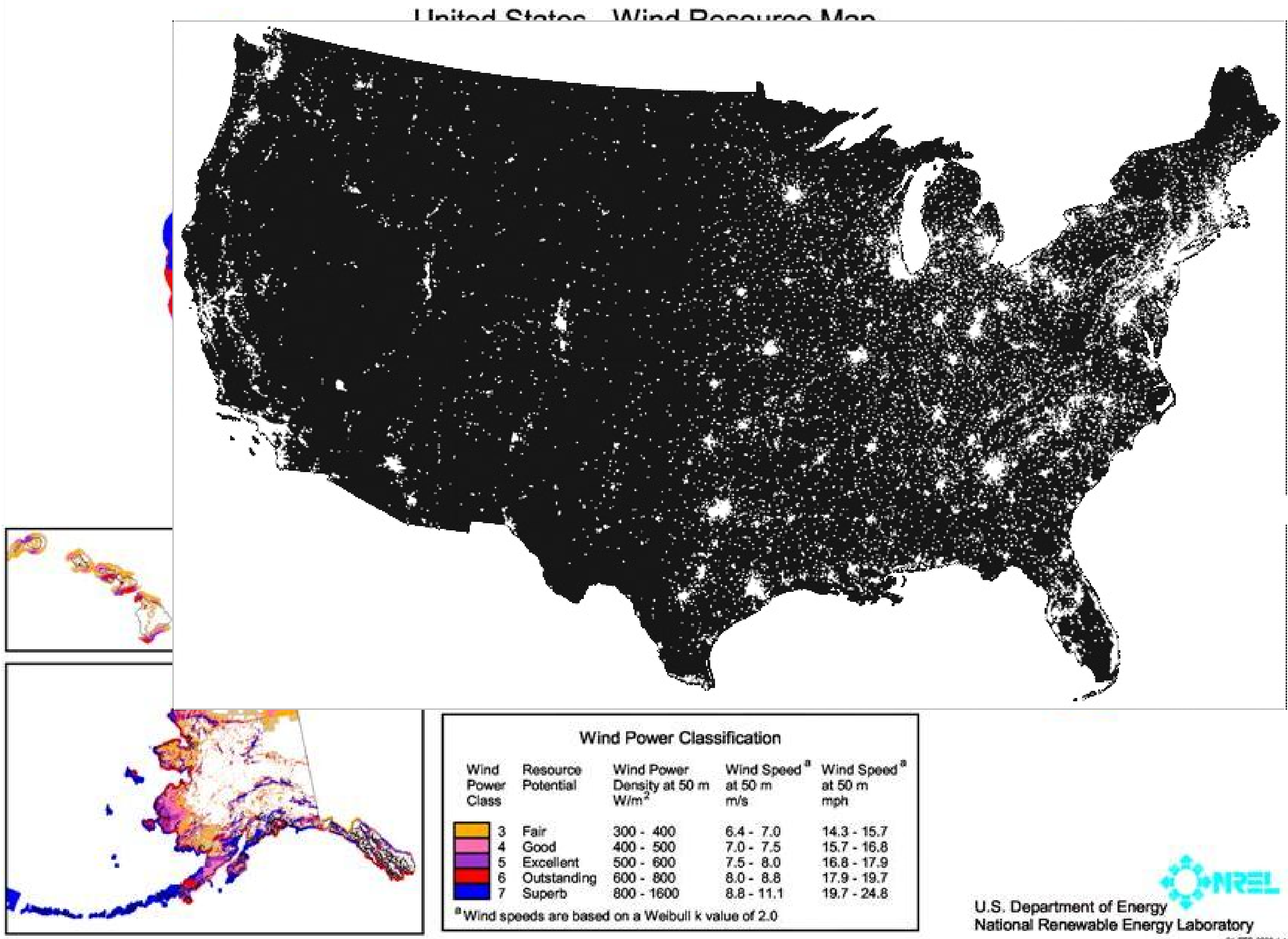
- Smart meters raise important questions of "who's in control." In some parts of Europe (e.g. the Netherlands) smart meters will be entirely under the control of the utility. Many of us feel that this is not how we should do it in the US.

- In the rush to install smart grid technology, there is a risk that we'll create vulnerabilities by deploying technology that lock us in before things have been adequately tested and debugged

We'll talk about both these issues in our final round-table session.

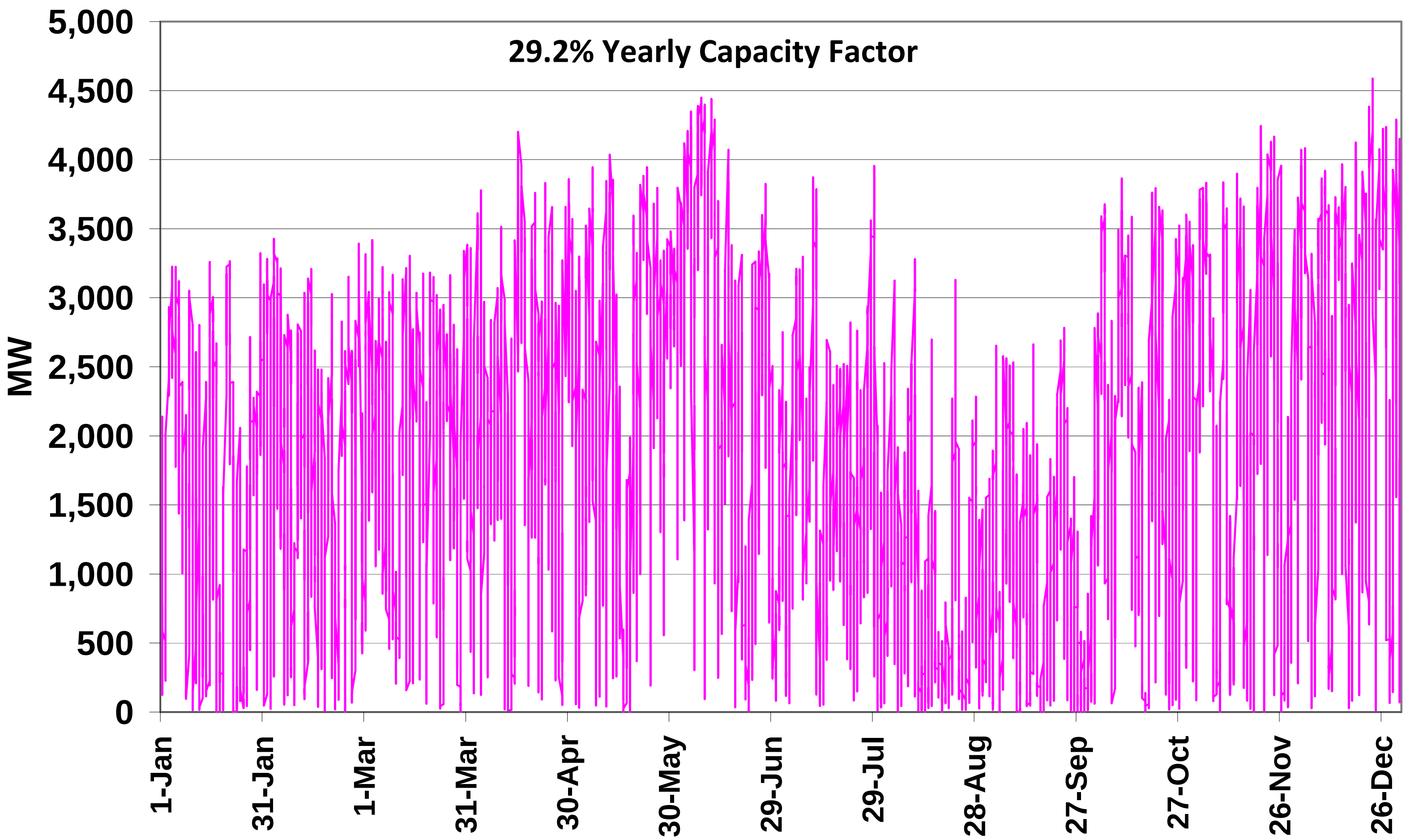
Using smart grid technology to support more and better use of wind

Using more wind will require a much smarter power system.



Wind is highly variable

Hourly output from 3000 Turbines in Texas added together throughout 2008

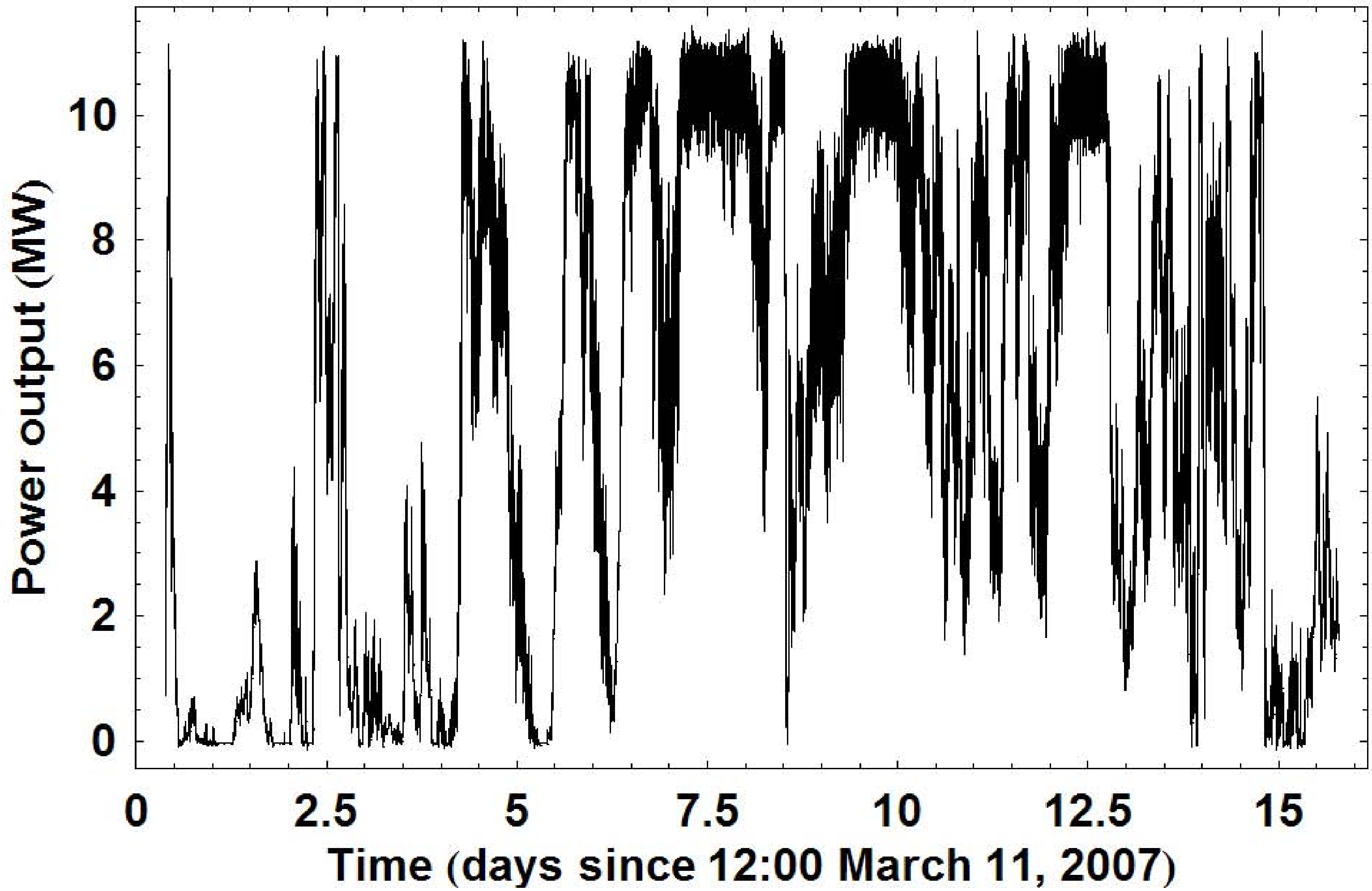


engineering and public policy

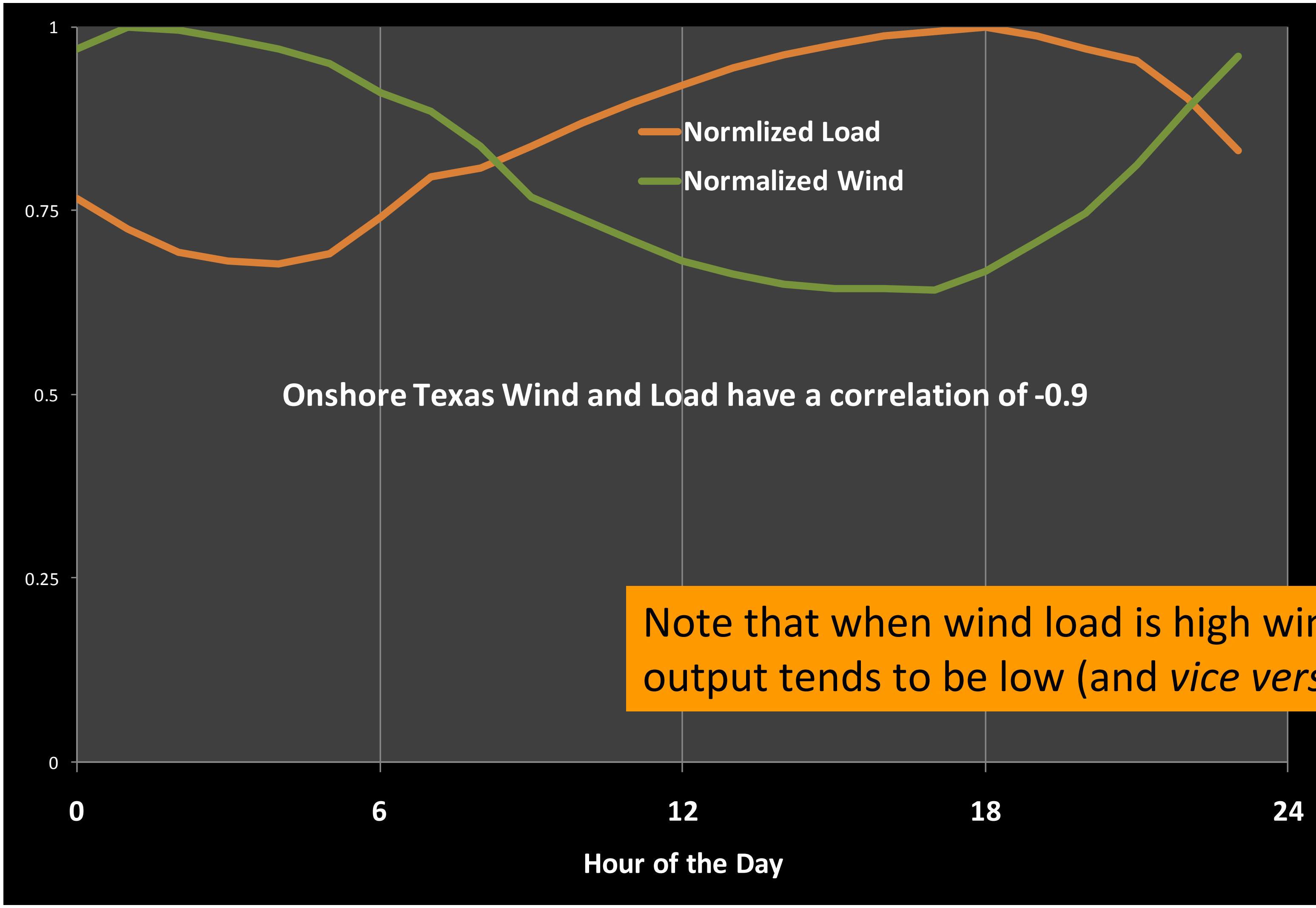
Preparing Technical Leaders to Address Policy Issues that Involve Science and Technology.

Electrical & Computer ENGINEERING

15 Days of 10-Second Time Resolution Data



Texas Load and Wind in 2008
(Averaged by Hour of the Day)



Note that when wind load is high wind output tends to be low (and *vice versa*).

engineering and public policy

Electrical & Computer ENGINEERING

Smart and Green

- Price signals and direct load control to individual loads can help cope with wind's variability.
- Thermal storage (like France's water heaters) can help night-time wind serve load.
- Charging plug-in vehicle batteries at night may also help night-time wind serve load.

Photo source: GM

- Both a smarter grid and smarter loads may help the grid cope with wider fluctuations around the nominal 60 Hz, making integration of wind less costly.

Smart and Green

- It may be possible to use the DC power from offshore wind in ways that dramatically change how grid power flows.
- Smart transmission systems may be better able to cope with the sudden calming of wind, or with its sudden return.

Using FACTS and smart control to move more power through the system

- Situation:
  - Increase of power consumption and exchange
  - Becoming harder and harder to build new transmissionn lines – need to move more power through existing lines
  - Availability of primary renewable energy sources not where loads are - change of power flows due to new generation
- Problem
  - Power flows according to Kirchhoff's laws
  - Transfer capacity is limited
  - Difficult to build new lines (right of way, „not in my backyard")

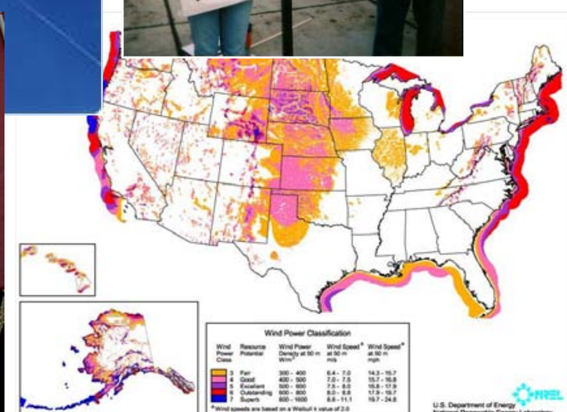



Image sources: http://www.nrel.gov/gis/wind.html; AEP; NYT;socialistaction.org

What are FACTS devices?

FACTS = Flexible AC Transmission System

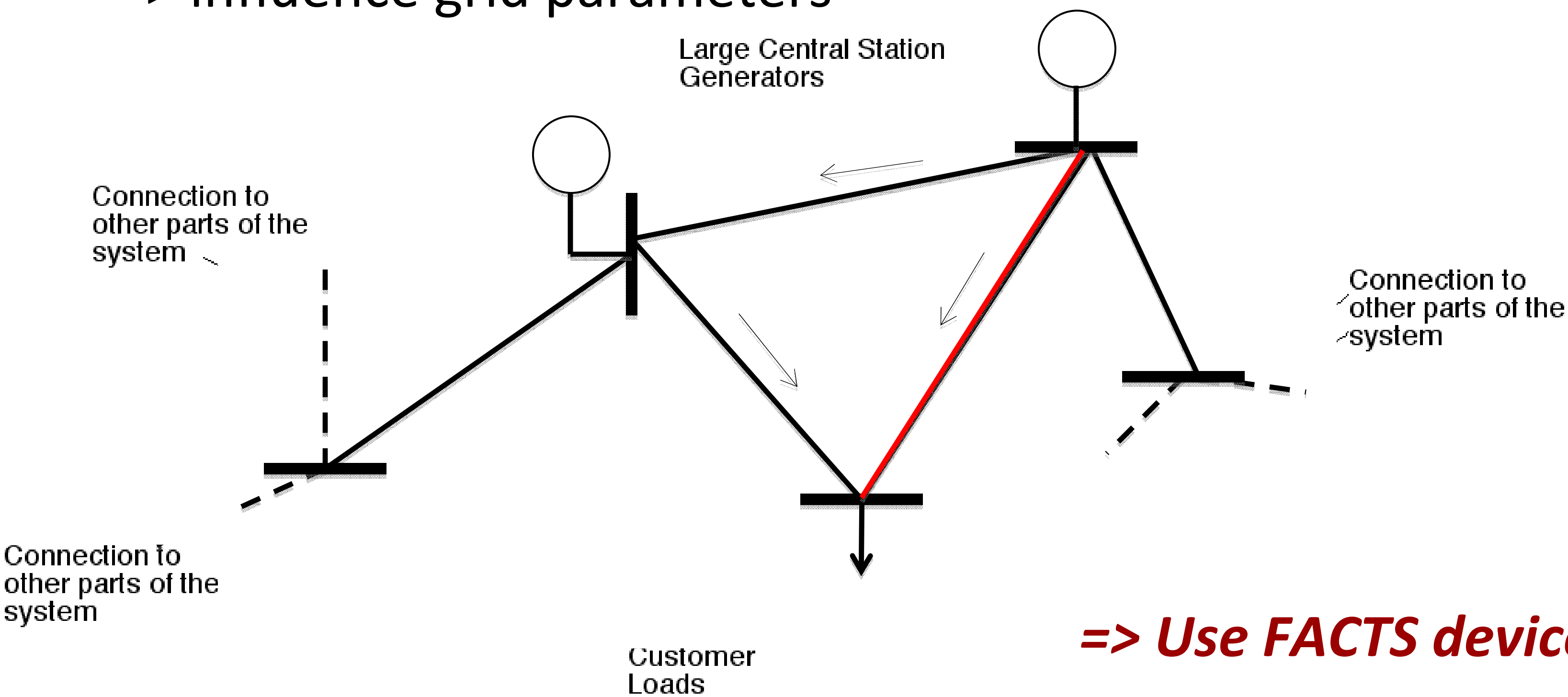
These devices use solid state power electronics to influence and control voltages and power flows in transmission systems.

Limited Capacity of Transmission System

- Transfer capacity of line is limited due to thermal limits

  => generation rescheduling

  => influence grid parameters

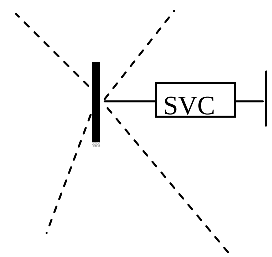


=> Use FACTS devices

Examples of applications

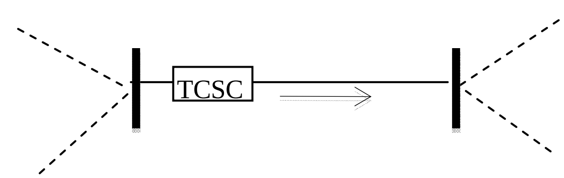
– Static Var Compensator (SVC)

- First installations in the 1970s
- Voltage support and stability enhancement
- Well established (~1000 devices installed)



– Thyristor Controlled Series Compensator (TCSC)

- First installation in 1992
- Increase transfer capacity and dampen interarea oscillations
- Not as well established



– Many other devices still rather of academic interest (UPFC, SSSC, ...)

Benefits of FACTS

- Transfer capacity increase (so can use existing lines more efficiently)
- Power flow control (so power can go where it is wanted)
- Voltage control
- Power quality improvement
- Stability enhancement (so the risk of blackouts is reduced)
- …

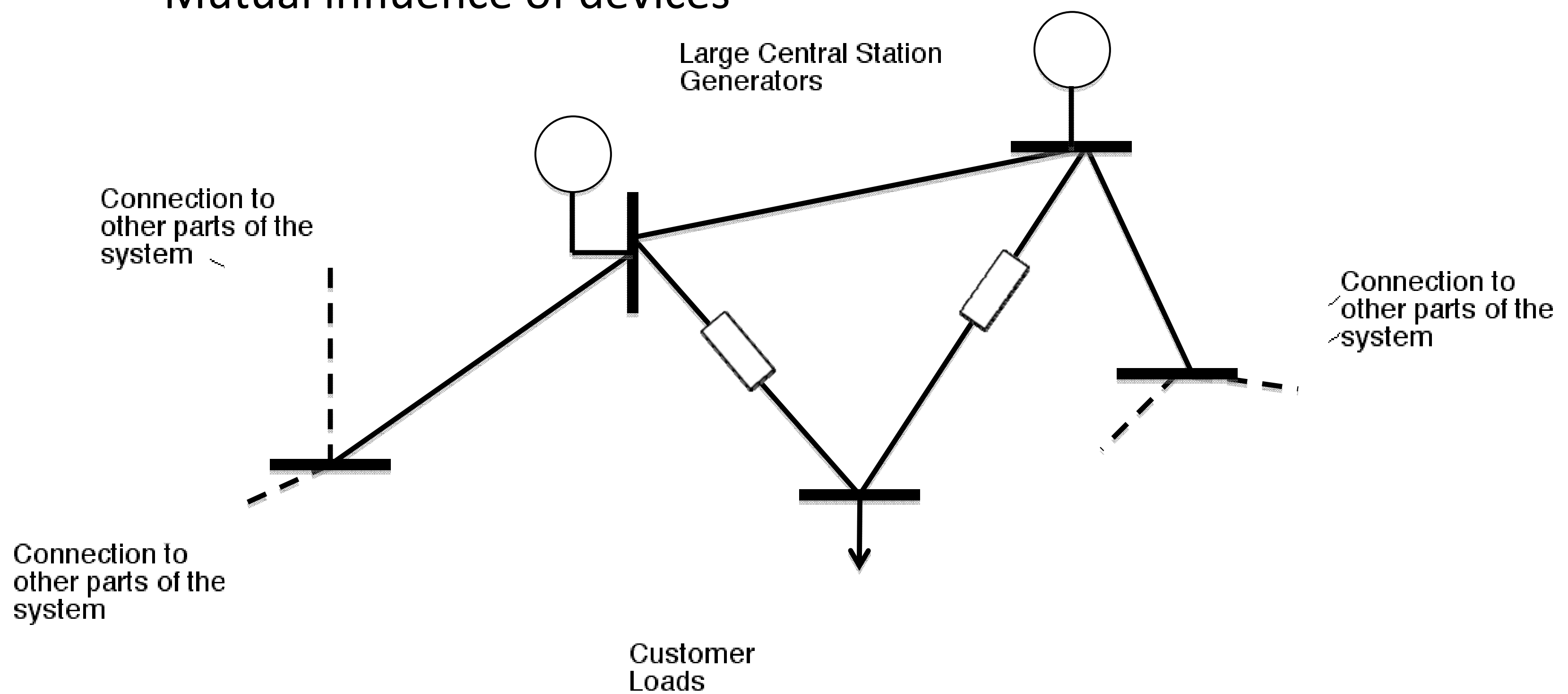
$\Rightarrow$ enabling changing power flows

$\Rightarrow$ possibly enabling favorable renewable generation locations

$\Rightarrow$ supplying increased consumption

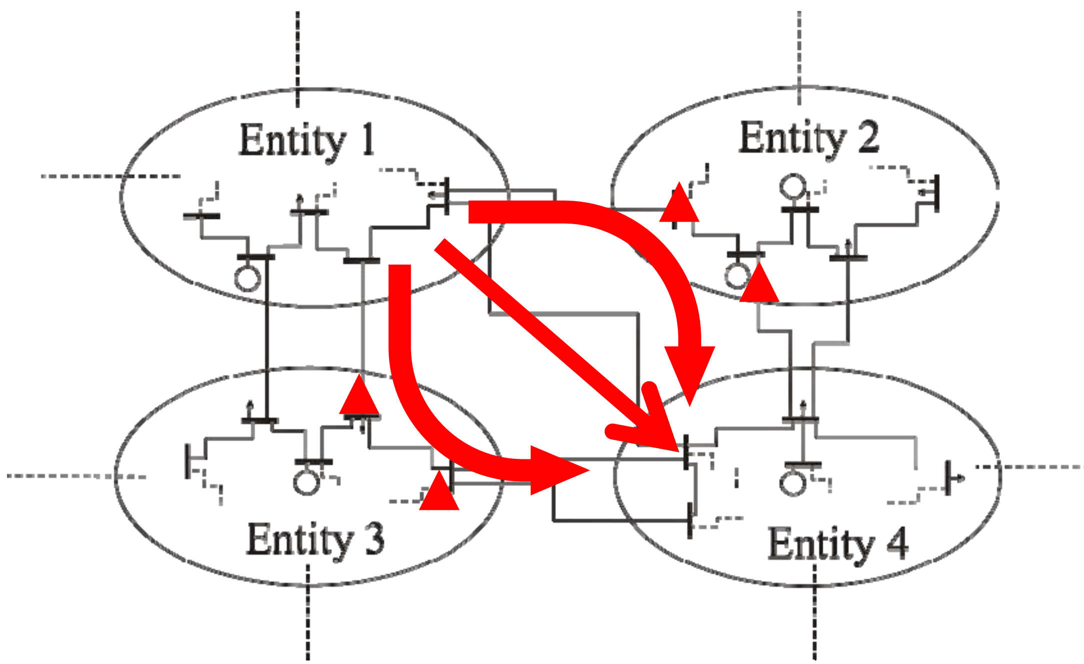
Control Considerations

- Choice of location
- Coordination
  - FACTS device influences power flows in surrounding grid
  - Mutual influence of devices



Control Considerations

- Power Grid is controlled by multiple entities
  => coordination among entities necessary



▲ Control Device

=> No benefit from devices

Using smart grid technology to improve the efficiency with which we use electricity

- Few consumers know the cost of using appliances – They just complain about the bill.
- Advanced Metering Infrastructure (AMI)

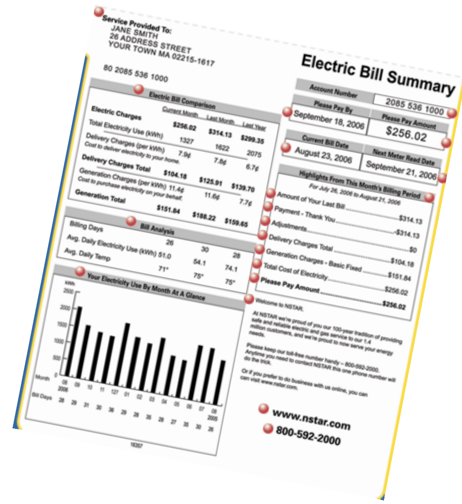
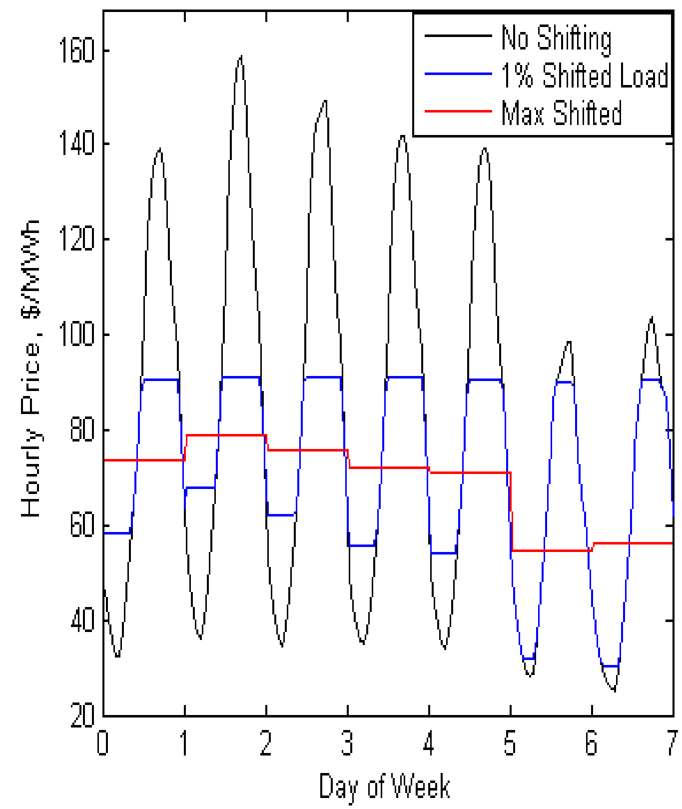


Image from thegreencarco.com

  - Allows customers to learn how much electricity they are using and have control over their bill.
  - Some programs compare their use with neighbors to show possible conservation
  - AMI can inform & empower customers

Using Smart Grid to Match Price to Cost

- Until recently, except for a few large industrial customers, customers faced prices that do not vary with generation cost
- This encourages high use at the hottest hours, which raises cost. In PJM 20% of capacity is used only about 100 hours per year.
- The cost of an additional kWh can reach $2 with rolling blackouts
- Studies show that many customers are sensitive to electricity price



Benefits of Smart Grid Variable Pricing

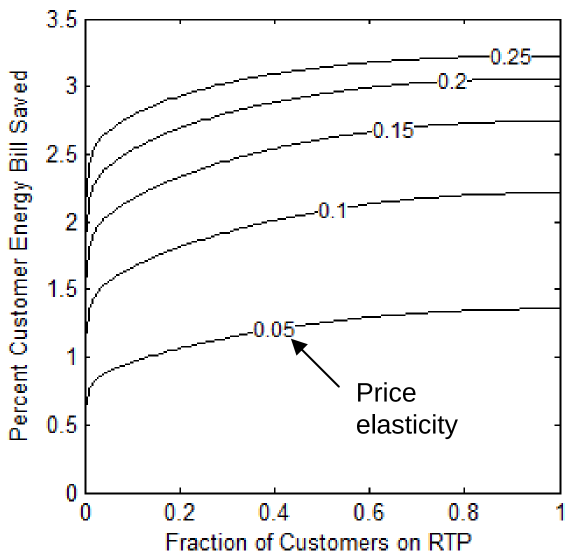
- Time of use (like cell phones), critical peak pricing (& rebates) & real time pricing inform and enable customers to reduce usage when generation costs are high.

Image from archiexpo.com

- For real time pricing, we would add an electronic energy manager that adjusts use to customer instructions as price changes.
- This system would increase reliability & power quality while lowering cost

Getting Benefits for the Smart Grid

- Smart meters & energy manager cost $150-400 to buy & install



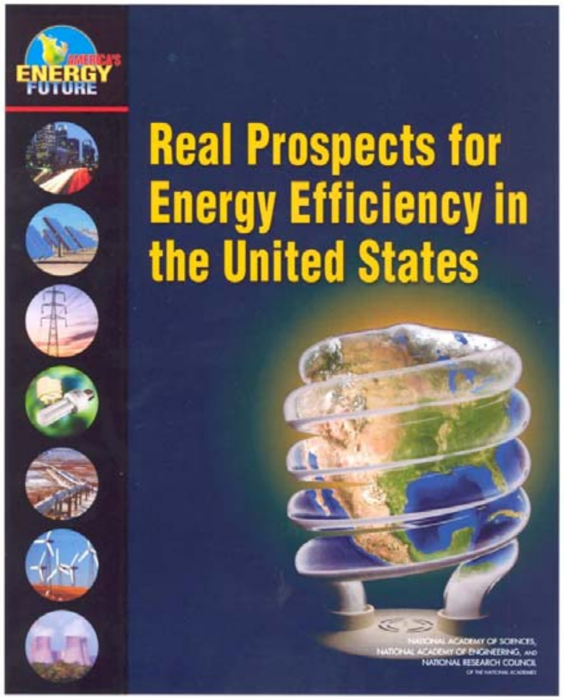
- After paying for the meter, the customer would save money only if she reduced use during times of high price. Thus, the smart meter should go only to customers with more than 2.5 kW of demand at peak times and have a price elasticity of at least -0.15

- If this is done, all customers benefit from the lower peak prices.

Intelligent Rollout of the Smart Grid

- Experiments have been done with time of use, critical peak pricing (rebates) and real time pricing. Only some customers react to price & average responsiveness is low.
- Providing all customers with smart meters will raise the bills for most customers.
- Used well, smart meters can deliver large benefits to almost all customers: Knowledge & empowerment, lower bills, more reliability.

The Smart Grid & Energy Efficiency



- A new National Academy of Science/Engineering study shows large potential for saving money & electricity through increased efficiency

- Formidable barriers have slowed or blocked the implementation of these efficient technologies.
- Informing & empowering customers & providing the right incentives is essential to achieving this efficiency.

Avoiding cyber vulnerabilities and making the smart grid more secure

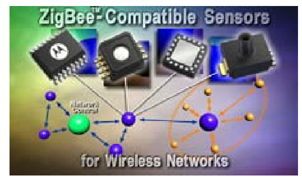
A "smart" grid will require the use of an extensive sensing, communication and computing infrastructure to collect, exchange and process sensor data.

Establishing "Trust" among components will be essential to guarantee safe operation of the new grid.

Smart Grid Components

Advanced Metering Infrastructure

Customer Area Network



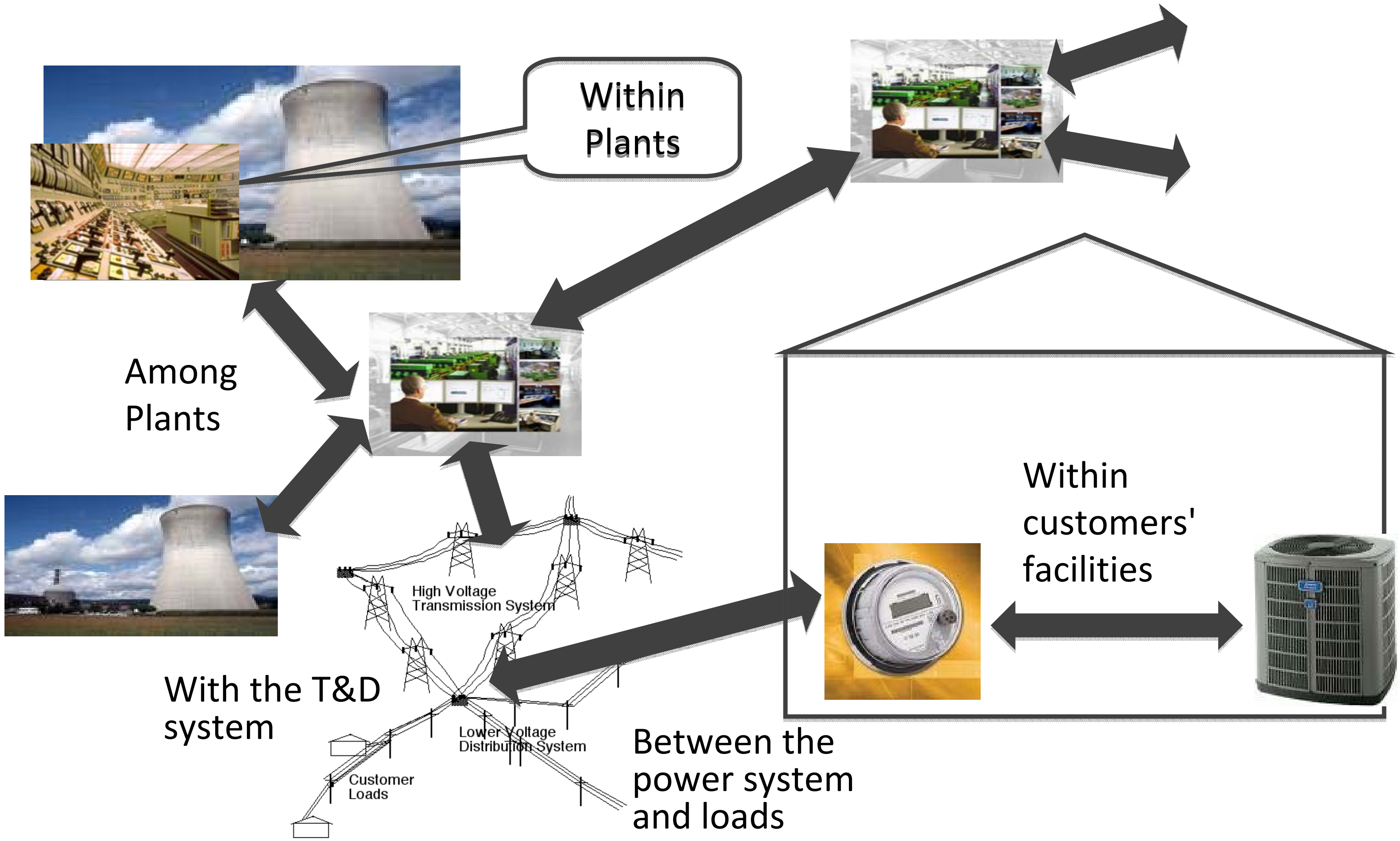
SCADA

Distributed Control Systems

Physical Plant

My presentation is on cyber security, but today physical vulnerabilities (ice storms, hurricanes terrorists, etc.) are a greater risk…as indeed they often are with IT systems.

Unprecedented Levels of Communication and Coordination



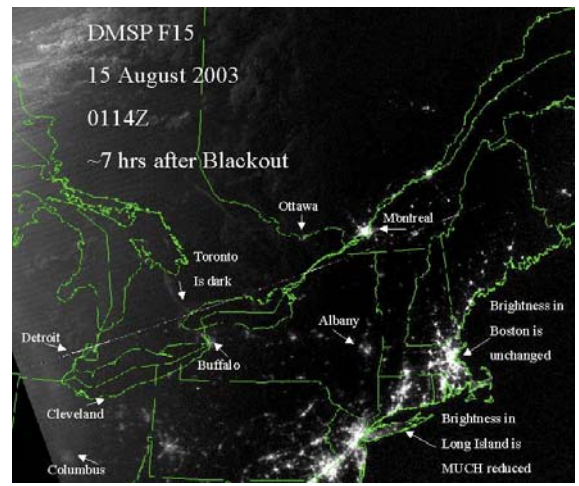
The Smart Grid: An Attractive Target For Attackers

"An attacker with $500 of equipment ... could take command and control of the [advanced meter infrastructure] allowing for the en masse manipulation of service to homes and businesses." - IOActive, March 21, 2009

"Hacking The Smart Grid" - DefCon 2009, by Tony Flick

Without good security:

Might use the internet to cycle several Mw of customers' loads on and off...



..and trigger a major blackout

Images from:forum.skyscraperpage.com and NASA

Security is Needed for Business

"it is paramount that smart grid devices and interoperability standards include protections against cyber intrusions .. that are designed from the start *(not patches added on)*."

- Patricia Hoffman, US DOE, in Testimony to House, July 23 2009

"Merit Review Criteria:
…Addressing Interoperability and *Cyber Security* (20%)"

Stimulus Package Allocated 4.5 Billion for the Smart Grid. One vehicle, the Smart Grid Investment Grant Program Funding Opportunity Number: DE-FOA-0000058

Security in the Smart Grid

- **Advanced Metering Infrastructure**
- **Customer Area Network**
- **SCADA**
- **Distributed Control Systems**
- **Physical Plants**

AMI Security Specification 1.0.1

Security Services

- What is the current usage (Availability)
- Is the meter lying? (Integrity)
- No unauthorized party should read my meter? (Confidentiality)
- When was the last time I heard from a meter? (Accounting)
- Does this look right? Is the load unusual? (Anomaly & Attack Detection)

Security in the Smart Grid

- Advanced Metering Infrastructure
- Customer Area Network
- SCADA
- Distributed Control Systems
- Physical Plants

ZigBee & HAN Security

- Are you authorized to shut down the alarm? (Available & Authentication)
- Can others snoop on my HAN settings? (Encryption)
- I am a new fire alarm. Lets talk. (Key Management)
- How do I set this thing up? (Usability)
- Only dad can turn up the air conditioner (Access Control)

Security in the Smart Grid

Advanced Metering Infrastructure

Customer Area Network

SCADA

Distributed Control Systems

Physical Plants

"Securing DCS/SCADA is a national priority." – The National Strategy to Secure Cyber-Space (2003)

- Are all those commands real or a DoS? (Availability)
- Will that break the system? (Survivable and Available)
- Are you an real tech? (Authentication)
- Are you authorized to disable that functionality? (Access Control)
- Are you a hacker? (Intrusion Detection)

Security in the Smart Grid

Advanced Metering Infrastructure

Customer Area Network

SCADA

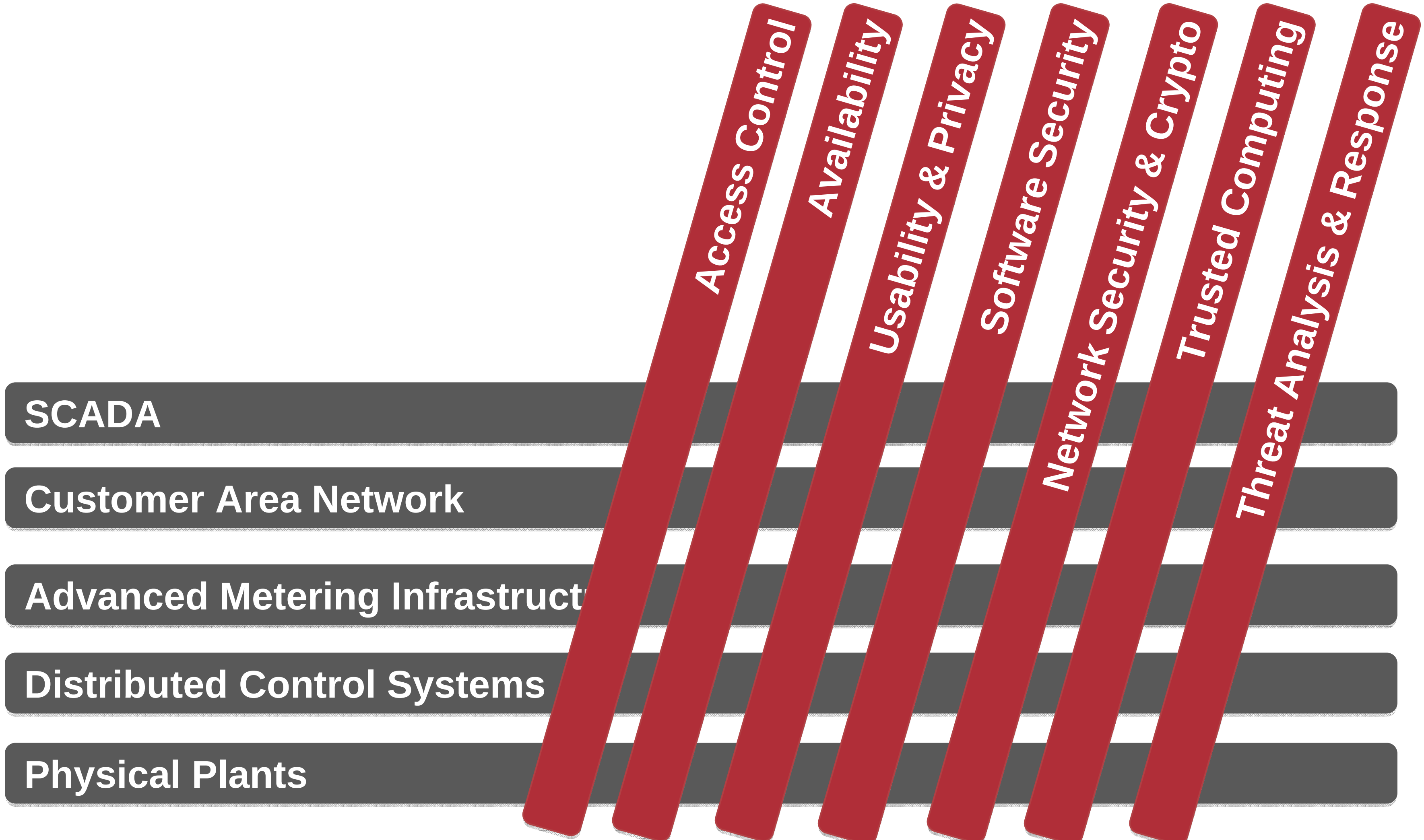
Distributed Control Systems

Physical Plants

NERC Cyber Security Standard Compliance for Bulk Power Systems

- How can I update the software without downtime? (Availability)
- Who are you? (Authentication)
- Should I have this modem connected? (Vulnerability Assessment)
- System 2.0 came out. Should I install it? (Up-to-date patches)
- Has our system been hacked? (Intrusion detection)
- What did the hacker do? (Accountability)

Smart Grid Security:
@ Intersection of Fields



Questions

- We know how to make the "smart grid" very secure, but as we rush to get hardware into the field, will we build in vulnerabilities because we have put lots of insecure systems in place?
- Who will own and operate the ICT infrastructure to support smart grid?
- How will Trust be established?
- Are market forces sufficient to guarantee a minimum security standard? Is regulation needed?

Some Bottom Lines

- Advanced electronics and communication have transformed fundamentally much of modern life and the services we enjoy. Their full-scale application in electric power systems, now being called "smart grid," is still in a very early stage.
- When people use the term "smart grid" they are often talking about *very* different things including:
  - more intelligent monitoring and control of the high voltage network;
  - monitoring and automation of distribution systems including selective load control and "islanding" during outages;
  - the use of real-time "smart" meters and the automated control of traditional and newer loads such as PEVs.

Bottom Lines…(Cont.)

- Greater use of sensors and intelligent control of both the grid and of loads, will likely be an important part of making it possible to integrate large amounts of variable wind generation into power systems.
- Greater use of advanced sensors and intelligent control will also be essential to making the transmission and distribution systems more robust and reliable.
- Flexible AC Transmission System (FACTS) devices, together with advanced advanced sensors and intelligent control can assure that power flows where we want it. FACTS can also move more power through existing lines. This can improve reliability and reduce the need to build new transmission lines.

Bottom Lines…(Cont.)

- Smart meters and advanced control systems can help customers use electricity more efficiently. Not all customers need to have these capabilities right away. Installation at roughly 20% of large flexible loads can get about 80% of the benefit. Done right, all customers would benefit from lower prices.

- As more and more information and communication technology gets added to the power system, vulnerabilities to accidental or intentional cyber disruption grow. These vulnerabilities can be dramatically reduced if security is addressed as an integral part of system design - not dealt with as an afterthought.

- While cyber security if very important, so too is the physical security of the power system - especially substations and the transmission system. Unfortunately, because physical security is less "sexy," it is too often ignored by policy makers.

Round Table Discussion
Two Key Policy Issues:

1. Who is in charge? When and about what should the customer get to choose and when should power companies make the decisions?

2. Are there policy choices that can minimize cyber vulnerabilities? In the rush to implement smart grid technology, many utilities and suppliers are implementing systems that have not been adequately designed or fully debugged. What can policy makers do to minimize the risks?