Sustainable Electric Power Systems in the 21st Century: *Requirements, Challenges and the Role of Smart Grid Technologies*

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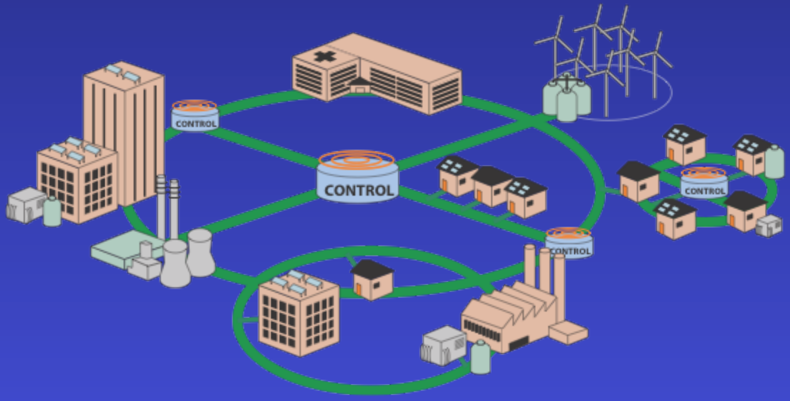
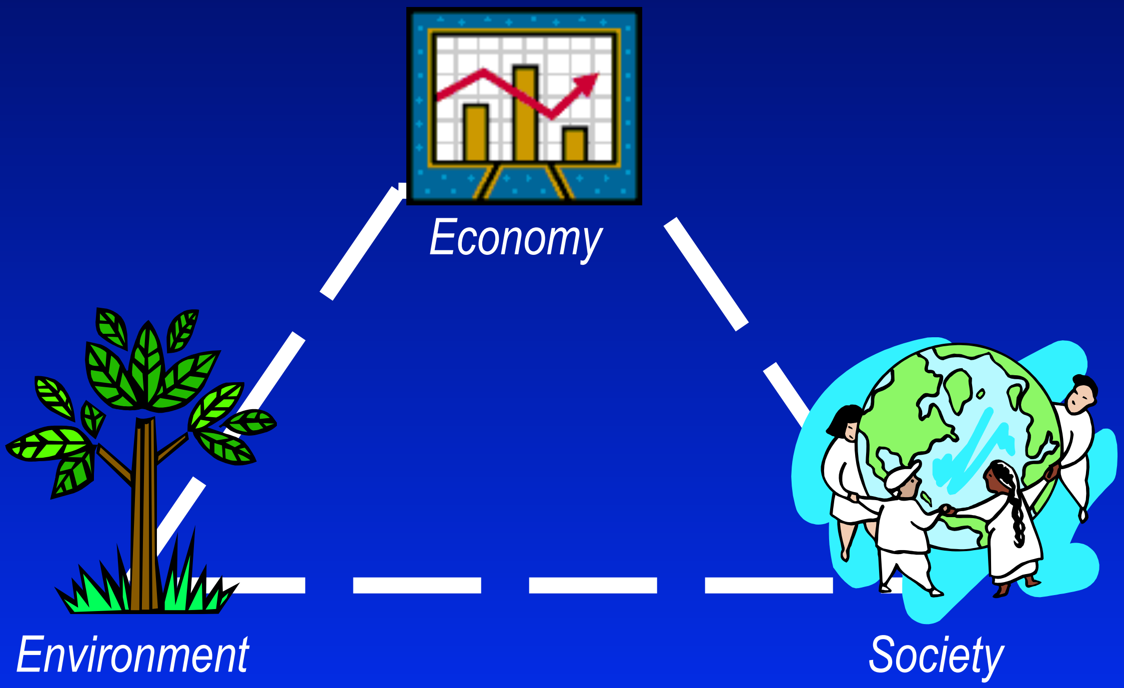


Power Systems in the 21st Century

- The electric power industry:
  - humble beginning in the 1880s; grown into one of the largest industries
- Has done a very good job of meeting the energy needs of the 20th century:
  - electricity has become a basic necessity in modern society
- Has had an adverse impact on the natural environment
- Industry now undergoing major restructuring
  - shift from monopolistic to competitive structure
  - new economic and social pressures
- Need to refocus business so as to meet energy needs of society in a way that leads to long-term "sustainability"

Sustainability

Involves balancing economic growth and social progress with the preservation of the natural environment



Sustainability of Power Systems

- Business practices have to be built on "three pillars" of sustainability:
  - environmental sustainability
  - economic sustainability
  - social sustainability

- Our challenges, therefore, are to:
  - produce, transmit and utilize energy in an environmentally responsible manner
  - reduce cost by improving business practices and operating efficiency
  - enhance reliability and quality of power supply

Environmental Sustainability

We need to:

- Integrate "green thinking" into our way of life and business practices
- Minimize the environmental impact of power plants as well as all other equipment
- Maximize resource conservation
  - leads to environmental as well as economic sustainability
- Utilize energy in an efficient and smart manner !

Environmental Concerns Related to Power Generation

- Greenhouse gas emissions, global warming issues and local emissions
- Increasing dependence on renewable sources
- Significant increase in the use of natural gas and bio-fuels
  - What is the best form of their use?
- Revival of nuclear option

The general trend would be towards a "carbon-free electricity/hydrogen energy economy" !

Technology Drivers that will Help Meet Future Energy Needs

- Technological advancement and cost reduction, combined with novel applications of renewable energy technologies
  - Bio-energy**
  - Solar energy
  - Geothermal
  - Ocean energy **
  - Wind energy
- Energy Storage
  - advanced batteries
  - hydrogen

Technology Drivers (cont'd)

- Distributed Energy Technologies
  - Fuel cells, Microturbines, Solar PV
  - installed at points of consumption
  - reduction in peak demand and transmission costs; improvement in power quality and security
- Technologies for <u>complementary use</u> of electricity and hydrogen as <u>energy carriers</u>

Ocean Energy

- Forms of ocean energy
  - tidal current energy: tides, currents, thermal, salinity gradient
  - wave energy
- Receiving much attention
  - many pilot projects worldwide
  - recent project at Vancouver Island in Canada using a novel turbine design:
    - friendly to aquatic life
  - potentially a large primary energy source: clean and cheap
- Typical costs
  - capital costs = $1000/kW to $2000/kW; energy costs = $0.35/kWh
- Integration with existing power systems presents technical challenges
  - not an insurmountable problem

Fuel Cells

- First demonstrated in 1839 by William Grove
  - combines hydrogen with oxygen from air to generate electricity with water and heat as by-products
- Hydrogen may be supplied from an external source, or generated inside fuel cell by reforming a hydrocarbon fuel
- Recent advances have reduced cost and size dramatically
- Wide range of potential applications
  - source of electric power in different sizes: micro fuel cells for laptops to large units connected to power grids
  - automobiles: fuel cell vehicles

The key device in the complementary use of electricity and hydrogen !

Typical Operating Characteristics of Fuel Cells

Type/Electrolyte	Efficiency	Temp	Capacity
Proton Exchange Membrane	30-35%	180°F	5-250 kW
Phosphoric Acid	35-40%	400°F	50-200 kW
Potassium/Lithium Carbonate	45-57%	1200°F	250 kW-30 MW
Solid Oxide	45-50%	1800°F	3 kW- 3 MW

- **Emissions** (lbs/MWh):

	NOx	SO_2
Fossil fuel plant	4.20	9.21
Microturbine	0.29	0.00
Carbonate fuel cell	0.013	0.00

Fuel Cells (cont'd)

- With co-generation, a carbonate or solid oxide fuel cell can achieve an efficiency of 60% to 70%
  - Can generate electricity directly from a hydrocarbon fuel by reforming the fuel inside to produce hydrogen

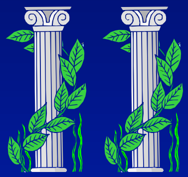
- Examples of fuel cell applications for power generation using bio-fuels:
  (a) waste from dairy processing plant (City of Tulare, California)
  (b) waste byproduct of beer brewing process (Sierra Nevada Brewing Co.)
  (c) biogas produced from food waste (Tokyo Super Eco Town)
  (d) biogas from water treatment plant (Point Loma Water Treatment Plant, San Diego, CA)

- Environmentally friendly alternative power generation source that can potentially yield lower cost electricity
  - Non-combustion, non-mechanical power generation process
  - Lower fuel and maintenance costs
  - "Smaller foot print"

Future of Distributed Generation (DG)

- Offer significant economic, environmental and security benefits
- DG can significantly reduce greenhouse gas emissions
- A study conducted by World Alliance for Decentralized Energy (WADE) compares the costs of future capacity development using a rigorous model for the U.S.:
  - 5.8 cents/kWh vs 8.9 cents/kWh for conventional central generation
  - Reduction of transmission costs in most cases
- Less vulnerable to natural calamities and disturbances causing power grid blackouts

Social Sustainability



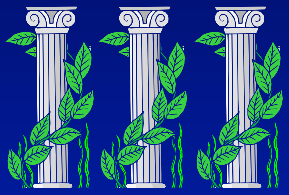
Social Sustainability

- Equity of customer access
- Ethical business practices*
- Governance and control

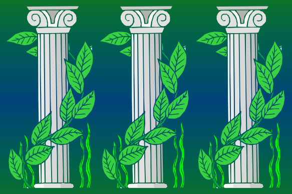
- Occupational safety and control
- Employee development

- Community development
- Partnerships/Networking*
- Support for universities and basic research*

Economic Sustainability



Economic Sustainability



- Efficiency, economy and service quality
  - More important in the new environment
- Efficiency and economy achieved by
  - More effective use of individual equipment and the integrated power system
- Service Quality
  - Need to have an infrastructure that will support the reliability and service quality demands of a digital economy
- "Intelligent Systems" can play a major role in meeting these requirements!

Smart Grid Concept
and
Enabling Technologies

Smart Grid

- A "Smart Grid" is an electricity network that intelligently integrates the actions of all entities connected to it:
  - generators, transmission and distribution equipment, and consumers

- The objectives are to :
  - better facilitate the integration of generators and storage devices of all sizes and technologies;
  - allow end consumers to play a part in optimizing operation of the system; and
  - deliver enhanced levels of reliability and quality of power supply.

Smart Grid Enabling Technologies

- Robust, Reliable and Secure high speed communication systems
- "Intelligent" electronic devices, monitors and algorithms for online condition assessment and initiating corrective actions
- Advanced digital technologies

Smart Grid Application Domains

1. Implementation of Advanced Metering Infrastructure:
   - Load Management

1. Integration of Distributed Resources and formation of "Microgrids"

2. Effective use of equipment: condition assessment, performance enhancement and life extension

3. Enhancement of Integrated Power System Performance

Advanced Metering Infrastructure

- Smart Meters:
  - Allow consumers to track their energy use and participate in load-shaping strategy and energy-savings program
  - Reduction in the expense of online meter reading

- Real-time pricing/hour ahead emergency pricing with *“Home Energy Dashboard”*
  - Time-of-use-pricing provides a financial incentive for consumers to shift some electricity usage from on-peak periods to off-peak periods

Distributed Resources and Microgrid

- Smart Grid technology will <u>facilitate integration</u> of distributed resources:
  - **Distributed Generation:** solar; microturbines; fuel-cells using hydrocarbon fuels
  - **Energy Storage Devices:** large batteries (VRB); hydrogen (electrolyzer, fuel cell)

- **With increase in Distributed Energy sources and ability to intelligently integrate various distributed resources, formation of "Microgrids" has become a reality!**

Examples of R&D Work Addressing the Enhancement of Effective Use of Individual Equipment

Technologies for More Effective Use of Equipment

Much of the power system infrastructure and assets are 35 to 50 years old.

The following technologies contribute to more effective use of equipment, operating efficiency and reliability:

- Automated pro-active monitoring systems for maintenance and prevention of failures
- "Intelligent systems" technology for equipment diagnostics
- Improved methods of life extension, uprating and efficiency enhancement
- Reliability-based asset management

Example: On-Line Monitoring of Transformers

- Catastrophic failures are costly
  - replacement costs, revenue loss, environmental impact
- On-line monitoring and condition assessment based on:
  a) monitoring oil to detect condition of insulation
  b) frequency-response characteristics using system perturbations
- Intelligent systems software for analyzing measured data and identifying any impending problems and transmitting the information to control centers
- Early detection of incipient failures
- Prevent unscheduled outages and costly catastrophic failures

On-Line Transformer Oil Conditioning and Life Extension

- Transformer oil/paper ages with time and temperature
- Aging accelerated by moisture, acids, impurities and contaminants
- Condition of paper determines life of transformer
- Continuously remove accelerants from oil to retard aging process
- Extends life of transformers by at least 10%

Performance of Integrated Power Systems: Challenges and Solutions

Effective Use of Integrated Power Systems: Challenges

- Reliable, secure and efficient operation presents many challenges in a competitive "market" environment
  - many entities with diverse business interests
  - system expansion and operation driven by economic drivers
  - inadequate transmission and infrastructure enhancements
- Power systems are physically very large complex systems
  - cover large geographic areas: *continental power grids*
  - millions of devices requiring harmonious interplay
  - exhibit complex modes of instability

Power System Security

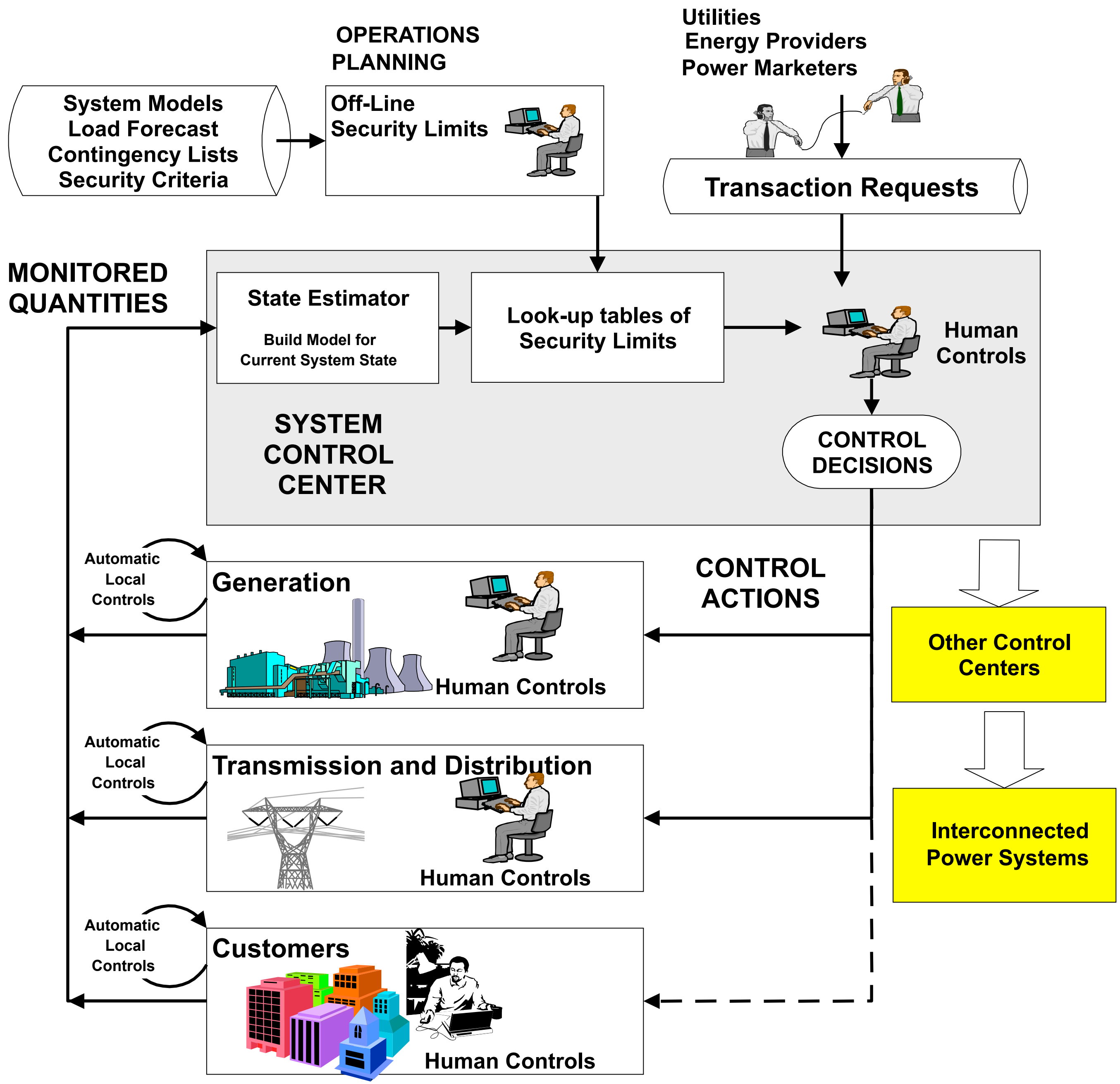
- Major concern since the infamous 9 November 1965 blackout of Northeast US and Ontario
- Presents new challenges in the present environment
- We had several wake up calls in recent years:
  - August 14, 2003 blackout of NE U.S.A. and Ontario
  - August 28, 2003 blackout of South London and Northwest Kent
  - September 28, 2003 blackout of Italy
  - September 23, 2003 blackout of South Sweden and Eastern Denmark
  - November 4, 2006 European Power Grid disturbance: UCTE network split into 3 islands

Technologies for Effective Use of Power Systems

- Improved system design and operation
  - robust, coordinated control design
  - adaptive protective relaying
  - on-line security assessment
- Improved emergency controls
  - defense against “extreme contingencies”
  - "self healing" systems
- Intelligent controls
- Real-time system monitoring and control
- Integrated information technology (IT) solutions
  - support complete business processes

Power System Control

- Overall control functions highly distributed
  - several levels of control
  - involve complex array of devices
- Human operators provide important links at various levels
  - acquire and organize information
  - make decisions requiring a combination of deductive, inductive, and intuitive reasoning
- Intuitive reasoning allows quick analysis of unforeseen and difficult situations and make corrective decisions
  - most important skill of an operator!


OPERATIONS
PLANNING
Utilities
Energy Providers
Power Marketers
System Models
Load Forecast
Contingency Lists
Security Criteria
Off-Line
Security Limits
Transaction Requests
MONITORED
QUANTITIES
State Estimator
Build Model for
Current System State
Look-up tables of
Security Limits
Human
Controls
SYSTEM
CONTROL
CENTER
CONTROL
DECISIONS
Automatic
Local
Controls
Generation
Human Controls
CONTROL
ACTIONS
Other Control
Centers
Automatic
Local
Controls
Transmission and Distribution
Human Controls
Interconnected
Power Systems
Automatic
Local
Controls
Customers
Human Controls

Intelligent Control of Power Systems

- Future power systems more complex to operate
  - less structured business environment
- Role of human operators becoming increasingly complex
- Current automatic controls do not have
  - "human-like" intelligence
- Add <u>intelligent systems</u> to conventional controls at various levels
  - learn and make decisions quickly
  - process imprecise information
  - provide high level of adaptation

Wide Area Monitoring and Control

- Advances in communications technology have made it possible to
  - monitor power systems over a wide area (WAMS)
  - remotely control many functions (WACS)
- Research on use of <u>multisensor data fusion</u> technology
  - process data from different monitors, integrate and process information
  - identify phenomenon associated with impending emergency
  - make intelligent control decisions
- A fast and effective way to <u>predict</u> onset of emergency conditions and take <u>remedial actions</u>

The ultimate "self-healing" power system !

"Smart Use" of Electricity/Energy

- Enormous opportunities exist for "smart" use of power leading to <u>efficiency</u>, <u>economy</u> and <u>conservation</u>

- Examples of "smart use" of energy:

  (a) "Buildings for Sustainability"

  - David and Lucile Packard Foundations Los Altos Project
  - "Living Building": designed to use of renewable "clean" energy generated locally, minimal reliance on the grid, efficient use of energy

  (b) "Better Buildings through <u>Integrated</u> Intelligent Systems"

  - Project commissioned by Industry Canada, coordinated by Continental Automated Buildings Association (CABA) and PRECARN
  - Reduced energy consumption and greenhouse gas emissions, improved safety and security of occupants, and reduced life cycle costs

Security of Smart Grids

- Need to address cyber security related issues!

- Increased dependence on information technology could lead to cascading failures from cyber attacks:
  - Denial-of-service on communication infrastructure
  - False data injection on telemetry or monitoring devices
  - Unwanted remote control of smart grid devices

- Possible approaches to addressing the security issues:
  - Intrusion detection and firewalls
  - Resilient control

Sustainable Power Systems in the 21st Century

Concluding Remarks

- Challenge is to produce electricity that is:
  - greener, cheaper, reliable and of higher quality
- Greater dependence on distributed energy technologies and renewable energy technologies
- Increased focus on using Intelligent systems for condition assessment and life extension of equipment
- Increased emphasis on the development of truly “Smart Grids”

Smart Grid Initiatives

Concluding Remarks (cont'd)

- Current smart grid initiatives largely tend to focus on smart meters and load shaping strategies
- In the long run we are likely to see more technology –rich initiatives leading to significant enhancement of overall power system performance
- Effective industry and university collaboration could have a significant impact on meeting some of the research and development needs