The Electrical Power Grid: Today and Tomorrow

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INTRODUCTION

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Introduction

- Electric Power Systems
  - Fundamental to modern society
  - Basic need for almost all ways of life and commerce
- Power Grid?
  - Network of wires and machines
  - Connects sources to consumers

Introduction

- Electrical Generation (Energy Consumption of the US)
  - 1940 – 10%, 1970 – 25%, 2002 – 40%, …
- Fundamental Dependence
  - The "Grid" now underlies every aspect of our economy and society
  - Worldwide production in 2008 at 15,000 billion kilowatt-hours (kWh) per year

Introduction - Challenges

- Loosely connected interconnected networks
- Increasing number of distributed resources
- Interconnection complexity
- # of sources, controls and loads growing
- These grids are among the most complex in the world
- Forecast for continued and extreme growth and further share increase of total energy.

Introduction - Challenges

- Over $1 Trillion investment needed over 10 years

- Three Overall Challenges
  1. Organization
  2. Ability to meet 25-50 year electricity needs
  3. Capacity to increase efficiency

THE GRID

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The Grid

- Commonly referred to incorrectly as the "power lines" between components
- Breakdown
  - Electrical Transmission System
    - Transports electricity from power plants to substations and consumers
    - Power lines
    - Substations
  - Distribution Facilities

The Grid - Stats

- As of 2008
  - In US
    - 15,000 generators, 10,000 power plants
    - 5,600 distribution facilities
  - North America has 339,000 km of high voltage wire. (>230kV)
- Demand since 1990 of +25% while transmission line construction -30%

The Grid - Structure

- Multi scaled, leveled hybrid system
- Levels
  - Transmission Level
    - >300kV and (100-300kV)
  - Subtransmission level
    - (100-300kV) but more medium voltage (5-15kV)
  - Distribution Level
    - (110-115V or 220-240V) and (1-100kV)

The Grid – Disturbances

- Adaptation known as modes
  - Normal
  - Involving Economic Dispatch
  - Load Frequency Control
  - Maintenance
  - Forecasting
- I.e. faults, instability, load shedding

The Grid - Challenges

- Large complexity
- Storage of electricity very difficult
- Instant availability and adaptation
- Generation types:
  - Base load
  - Peaking
  - Intermediate

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TRANSMISSION

Transmission - Challenges

- Losses up to 7.5%
  - Mostly due to heat
  - Combated by increasing voltage and decreasing current
- Power flowing through line must stay below line capacity to avoid failure
- As lines warm due to heat, they sag

Transmission - Challenges

- Line material
  - Aluminum Conductor Steel Reinforced (ACSR) – ***Currently***
  - New materials that transmit more, further with less losses.
- Ultimate goal
  - Transmission power densities for cables and conductors of 50 times ACSR.

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POWER SYSTEMS PHENOMENA

Power Systems Phenomena – Problems

- Cascading Failures
  - Local failure leads to widespread outage
- Develop better understanding:
  - complex phenomena associated with power network systems
  - Emergency controls and restoration
- Disturbances Costs $75 to $180 billion annually

Solutions

- Need to re-think grid structure and design
- Ability to monitor all components
- Ability to act on the monitoring data
- New sensor technology
- Phased approach to adaptation
- Machine automation, Smart Grid

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SELF HEALING SMART GRID

Self Healing Smart Grid

- Automated control of complex network
- Self-healing with:
  - Instantaneous damage control
  - Flexible
  - Reliable
  - Dynamic load balancing
  - Secure

Self Healing Smart Grid

- Challenges
  - Technological Challenge
  - New hardware
    - Monitoring (current, voltage, phase)
    - Actuation (breakers, switches, etc.)
  - Software
  - Cost

New Hardware

- Processor
  - One for every component
  - Generic and standardized method for connecting all components
    - i.e. Breaker, switch, transformer and busbar
  - Contains the permanent information on device parameters and status
  - When connected automatically reports itself to central control

Failure Communication

- Today
  - Some computerized control
  - Mostly manual telephone calls
  - >30s delay assessing system
- Smart
  - Automatic
  - Fast
  - Best solution

Failure Response

- Today
  - Isolation “islands”
  - Island must fend for itself
- Smart
  - All components communicate
  - Coordination during failure
  - Efficient use of available resources until link(s) restored

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FSM – FAST SIMULATION AND MODELING

FSM

- Self-awareness and Reliance by:
  - Faster-than-real-time look-ahead simulations
  - By performing what-if analyises
  - Integrated view of all data sources and their effects on the system
- Minimize severity/size of outages
- Shorten duration of brownouts/blackouts
- Enable rapid/efficient restoration

Research for CASs

- Complex Adaptive Systems - (CASs)
- CASs developed via research in:
  – Nonlinear dynamic systems
  – Artificial intelligence
  – Game Theory
  – Software Engineering

Smart Grid vision

- Awake
- Responsive
- Adaptive
- Price/Eco Smart
- Real-time
- Flexible
- Interconnected

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TECHNOLOGIES

Technologies

- Sensors
- Biotechnology
- Smart Materials
- Nanotechnology
- Fullerenes
- Information Technology

Sensors

- Wide range of chemical sensors needed
  - Air
  - Water (inlet and outlet)
- Electrical
  - phase/current/voltage

Smart Materials

- Monitoring of remaining “life”
- Fault Tolerant, Agent-based collaborative intelligence
- Function autonomously in a almost biological manner
- i.e. Piezoelectric polymers, shape-memory alloys, hydrogels, fiber optics, etc.
- FACTS

Flexible ac transmission (FACTS)

- Solid state
- Link integrated circuits
  - Scaled up by factor of 500 Million
- Power control devices
  - Voltage
  - Impedance
  - Phase angle of high voltage lines

Advanced Hardware

- Meters
- Sensors/monitors
- Motors – Superconducting
- Transformers – Universal?
- Computer and networks
- Mobile devices
- Smart equipment and appliances

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Nanotechnology

- Two focused directions
  - Energy Storage
    - Expectation that storage issue solvable
    - Larger energy densities possible than current batteries
  - Energy Saving
    - Small dimensions, better contact
    - Thermal conductivity improvements

Fullerenes

- Carbon molecule type
- High strength
- Toughness
- Highly conductive
- Future uses for transportation
  - Long fine “tubes” that are extremely strong and versatile

Future?

- Low-cost, practical electric and thermal storage
- Microgrids
- Advanced devices
- Fail-safe communications
- Cost-competitive fuel cell

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Future?

- Low-cost sensors
- Cost-effective thermal storage
- Thermal appliances plug and play
- High efficiency lighting/motors
- Enhanced portability through improved storage and power conversion devices

Conclusion

- Paradoxes
  - Technical
    - Supply and demand instantaneous
    - System complex, time-consuming
  - Economic
    - Deregulation often leads to system degregation
    - Lower price, high profit using existing system to limits, under investment

Conclusion

- Status quo not sustainable
- Evolution necessary to maintain
  - Quality of life
  - Economic Feasibility
  - Forecast Growth
- Risk of 20th century relic if nothing done

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