Electric Grid R&D Program at ORNL

Tom King

Manager, Electric Delivery Technology Program

Oak Ridge National Laboratory

OAK RIDGE National Laboratory

Oak Ridge National Laboratory evolved from the Manhattan Project

ORNL in 1943
The Clinton Pile was the world's first continuously operated nuclear reactor

ORNL is going through a major modernization

East Campus

Chestnut Ridge Campus

Science and Technology Park

West Campus

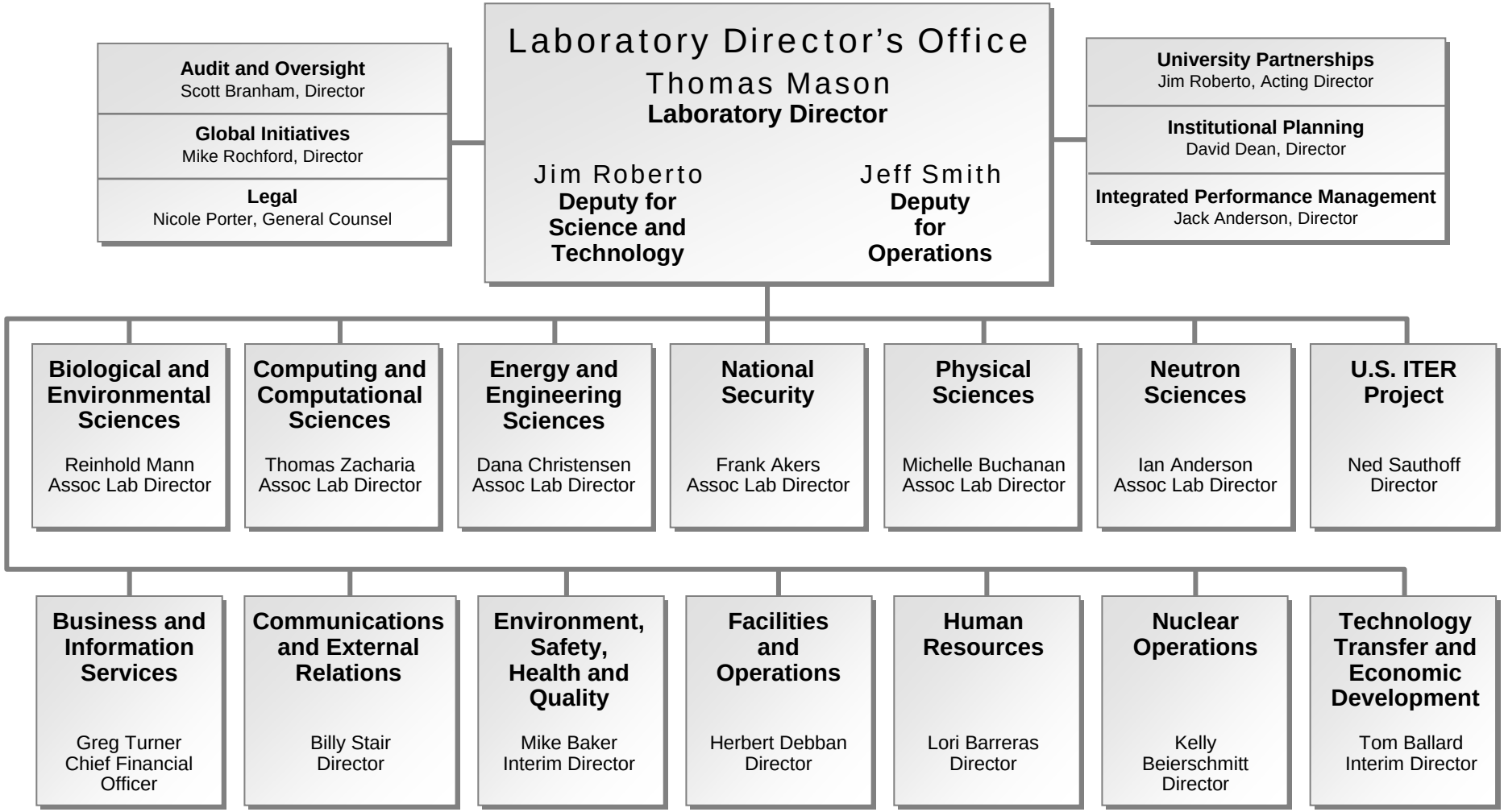
Today, ORNL is DOE's largest science and energy laboratory

- $1.1B budget
- 4,200 employees
- 3,000 research guests annually
- $300 million invested in modernization
- Work with over 600 companies

- World's most powerful open scientific computing facility
- Nation's largest concentration of open source materials research

- Nation's most diverse energy portfolio
- Bringing the $1.4B Spallation Neutron Source into operation
- Managing the billion-dollar U.S. ITER project

Oak Ridge National Laboratory



OAK RIDGE National Laboratory

Oak Ridge National Laboratory:
Energy research to power America's future

Near-term **Long-term**

Abundant, Affordable Domestic Energy

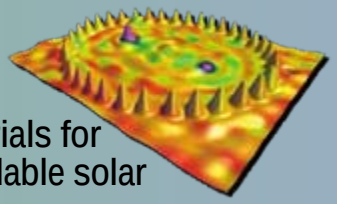
High-yield, robust biofuel crops

Closing the nuclear fuel cycle

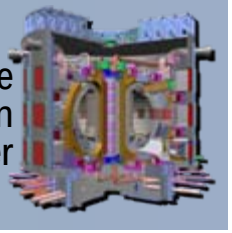
Sustainable nuclear reactors and fuels

Oil shale extraction technology

Nano materials for affordable solar



Inexhaustible fusion power

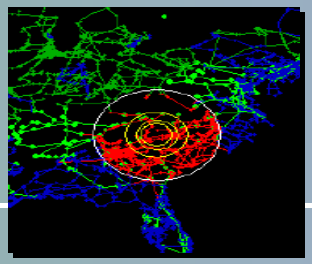


National Competitive-ness

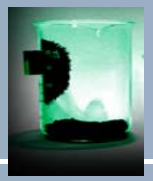
Net-zero energy houses

Efficient vehicles and engines

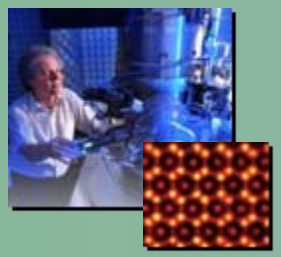
Smart, efficient electricity grid



Biotech and materials processes for efficient industry



Environmental Quality



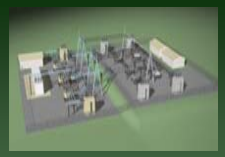
Cleaner coal plants and engines

Capturing and sequestering CO_2

ORNL performing R&D to assist DOE in improving electric grid reliability

Power Delivery Test Facilities


Advanced Conductor Test Facility


Power Electronics Test facility


HTS cable & subsystems


DE Systems (DECC)

Advanced Materials

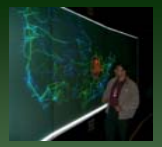

HTS - 2G wire & components


Power Electronics


Next-Gen components


Energy Storage

Visualization. Modeling & Analysis


VERDE - Transmission Monitoring


Computational Modeling & Controls


Transmission Reliability

National Security


Micro-grids – Reconfigurable Grid


Critical Infrastructures – Control System Security

Ensure the Reliability & Security of the Nation's Grid

- Reduce Transmission Congestion
- Improve Power Quality
- Reduce Major Outages
- Improve Restoration Times

Power Delivery Research Center:

Demonstrating the Reliability of Advanced Technologies

High Temperature Superconducting Cable Test Facility

- HTS cables and components, including terminations, joints, and cryogenic systems.
- Partnership with Southwire
- Facility used to test AEP Columbus Bixby HTS Cable (2006) and for testing Entergy HTS Cable (2011)

Distributed Energy Communication & Controls

- Demonstrate reactive power compensation from distributed energy
- Developing controls for voltage regulation to improve system reliability

Power Electronics Test Facility

- Demonstrate reliable operations of power electronics components
- Adjacent to recently energized substation
- TVA/ORNL/EPRI partnership

Conductor Accelerated Test Facility

- Advanced conductor testing to ensure operation over life of system
- High current, low voltage dc power induces thermal cycles on conductor

OAK RIDGE National Laboratory

Superconducting Wires and Applications

ORNL High-Temperature Superconductivity Program

Office of Electricity Delivery and Energy Reliability

Develop high-performance low-cost high-temperature superconducting (HTS) wires in long lengths

Demonstrate compact highly efficient HTS applications

HTS Wires

Flexible "single crystals" by the kilometer

Integrate metallurgy, semiconductor- and nano-technologies

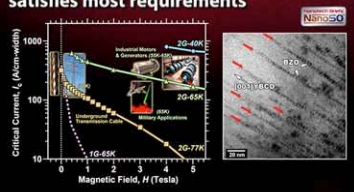
ORNL Template R&D 100

Textured Templates

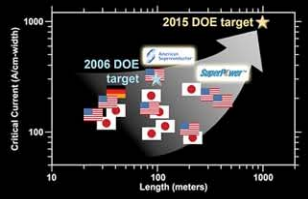
World Class Performance

Utilize nano-defect engineering & materials by design

Lab-scale wire with aligned nanodots satisfies most requirements



Long length wires set World Records



Superconducting Electric Power Equipment

Half the energy losses, half the size and lower operating costs compared to conventional units

Columbus Triaxial HTS Cable

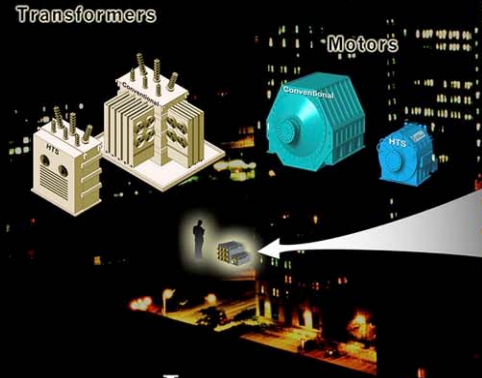
- World Records:
  Most compact,
  Highest current density,
  Lowest cost design

HTS Transformers

- No oil to ignite
- Urban siting

HTS Motors

- Weight redistribution
- Efficient & stable



HTS Fault Current Limiters

- Fail-safe operations
- Better power quality

Contact
Dominic Lee
(865) 241-0775
leedf@ornl.gov
www.ornl.gov/sci/htsc/hstc.html

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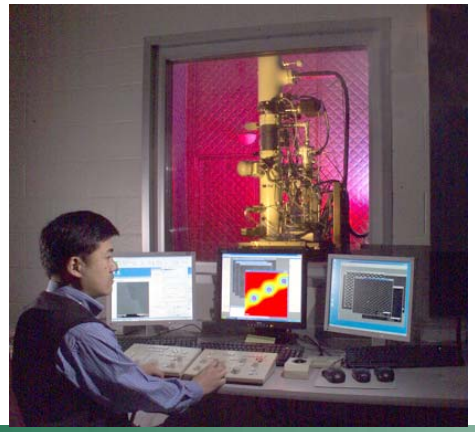
Electric Grid R&D Program at ORNL

Advanced Materials

The High Temperature Materials Laboratory provides world-leading materials capabilities

- Funded by Office of FreedomCAR and Vehicle Technologies Program
- Six user centers to provide materials-related solutions for engine/vehicle systems being developed
  - Diffraction User Center
  - Machining, Inspection, and Tribology User Center
  - Materials Analysis User Center
  - Mechanical Characterization and Analysis User Center
  - Residual Stress User Center
  - Thermophysical Properties User Center



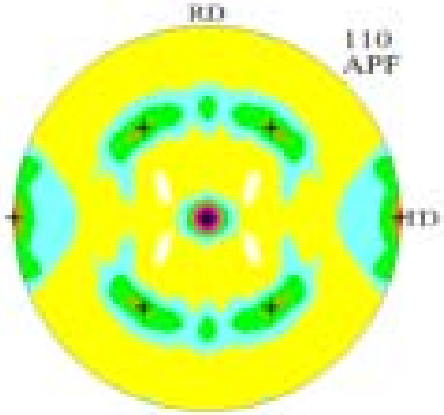
ORNL's Research and Development on Modular Transformers

- Aging Infrastructure
  - Current average age of transformers range from 25-40+ years for small and large units
  - Majority fail between 10-30 years of age
- ORNL working with Waukesha Electric Systems to develop modular concept
  - American Electric Power support
- Multiple configurations for both high and low voltage ratings, improved materials
  - Increased flux density in core steel
  - High temperature synthetic insulation

Shear rolling results in the formation of desirable grain orientation for core steel

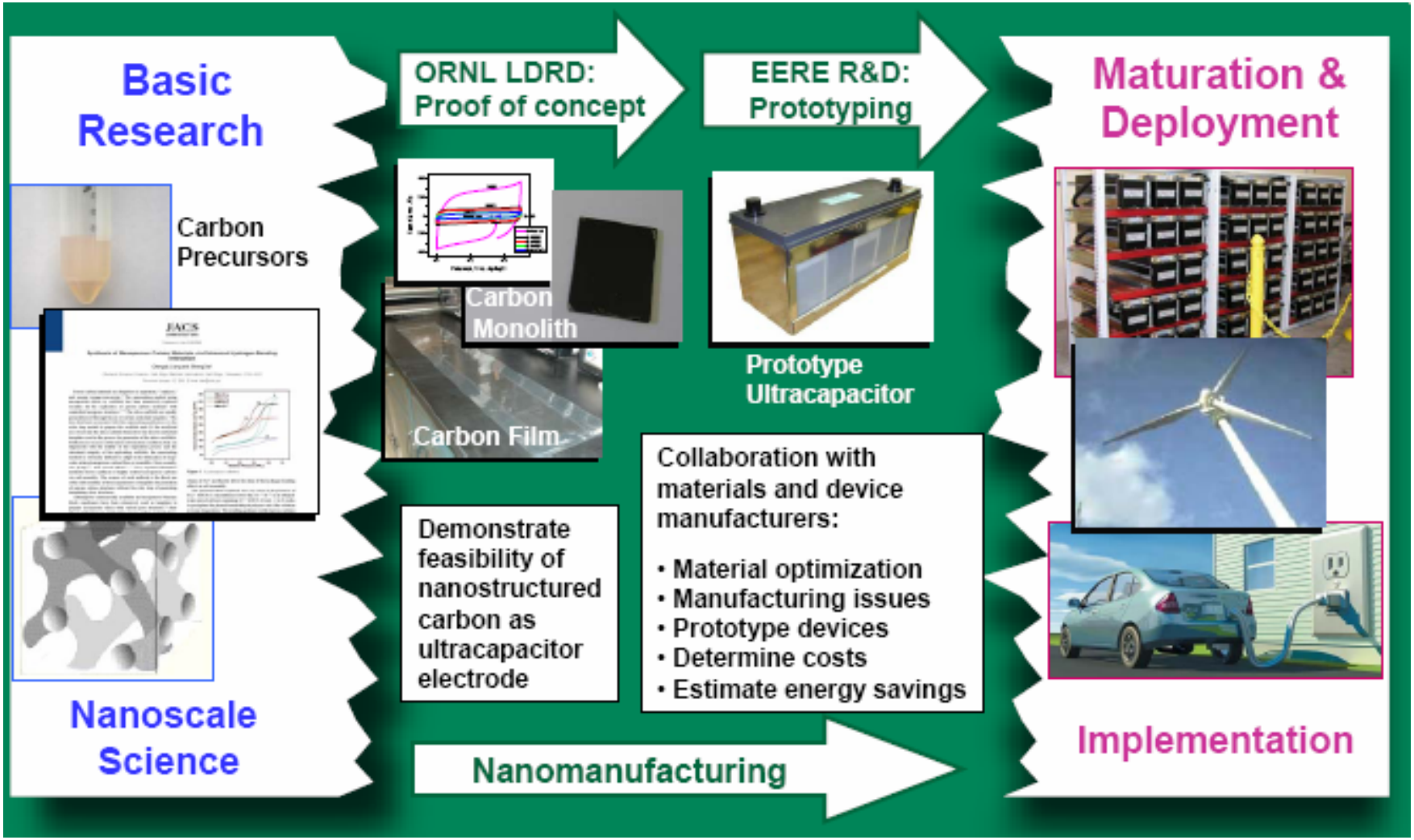
- Iron-Silicon steel sheet for shear rolling obtained from AK steel
- Sheets processed using a modified rolling set up at ORNL
- Computational modeling was used to predict the optimum thermo-mechanical processing path for obtaining desirable grain orientation
  - Cube-on-edge (Goss) orientation is required for optimum magnetic performance
- Initial shear rolling experiments using computed deformation path give grain orientation close to Goss
- New process can potentially eliminate expensive and energy-intensive annealing steps used in the current industrial process for core-steel

Rolling mill with rolls of unequal size

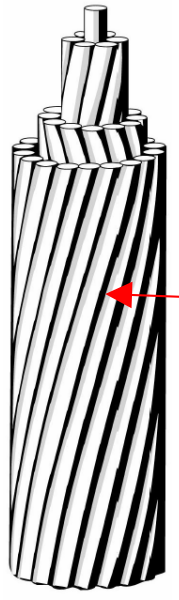


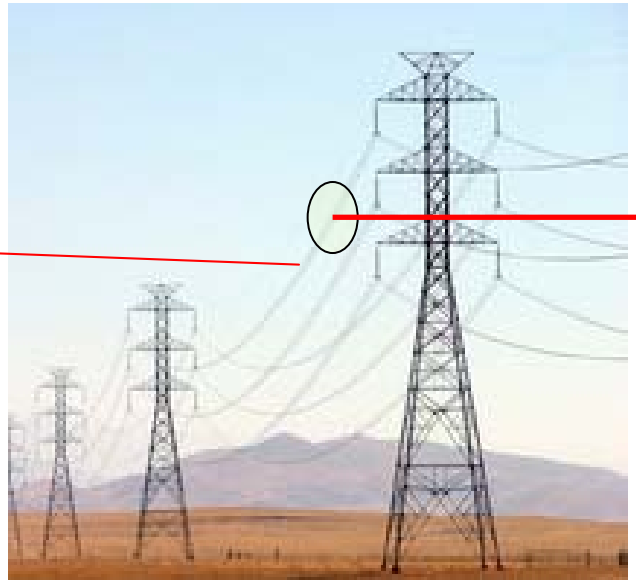
Cube-on-edge orientations obtained by shear rolling

Nano-materials to Ultra capacitors



Remaining Life Analysis Advanced Conductor EPRI Project





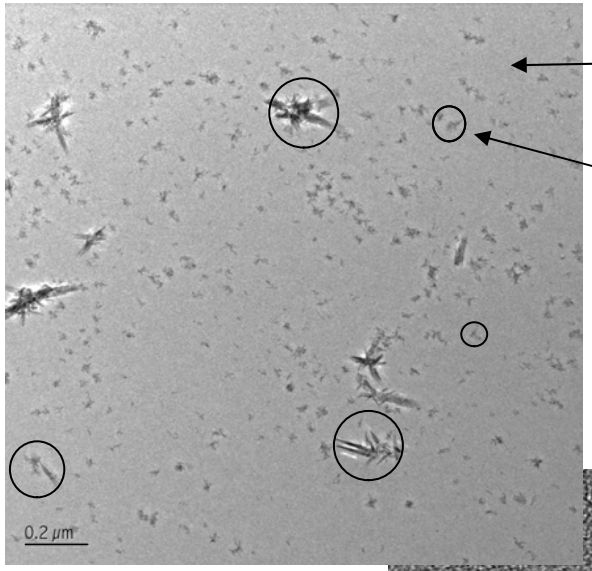
Compression splice connector fittings: (top) the two-stage fitting (TSC), (bottom) the single stage fitting (SSC).

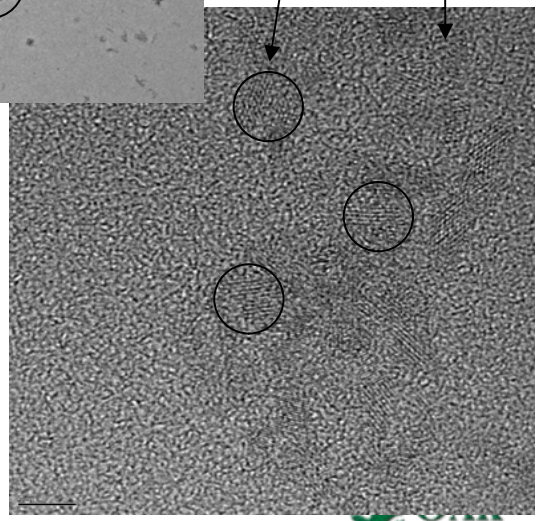
Weakest Link in A Conductor System – Splice Connector

Especially at higher operating temperature!

Novel solid dielectrics for capacitors and electrical insulation

- Replace micron-sized filler metal oxide particles with nanosize oxide particles
- Nanodielectrics
  - New class of materials
  - Nanometer sized particle filled polymeric materials
- Improved electrical performance
  - High dielectric strength
  - More reliable
- Large design window





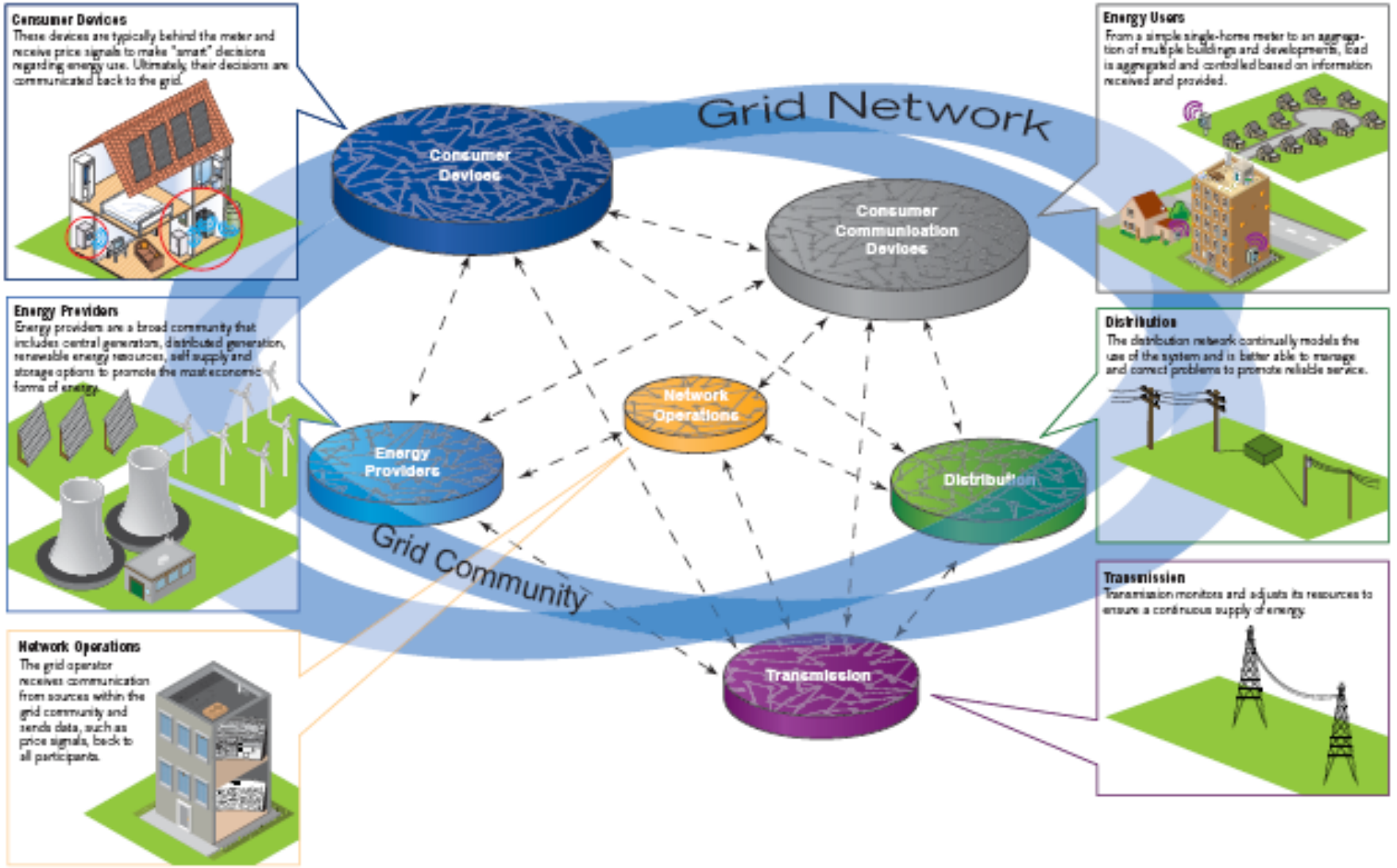
In *situ* synthesized titanate nano-particles filled polyvinyl alcohol

Electric Grid R&D Program at ORNL

“Smart Grid” Research and Development

OAK RIDGE National Laboratory

Modernizing the Electric Grid



PJM Interconnection

OAK RIDGE National Laboratory

ORNL was involved in the first fully integrated distribution automation system

- DOE funding from Office of Energy Storage and Distribution
  - FY82-FY88
- Project Team
  - ORNL
  - AUB, Athens Utilities Board
  - TVA, TVPPA, EPRI
  - Baltimore Gas & Electric
- Industrial Advisory Committee
- Athens Utilities Board (1985)
  - Municipal utility for the city of Athens, Tennessee
  - Population of 30,000 with 10,000 electric customers
  - 90 MW peak load
  - Three substations with 11 feeders

Athens Automation and Control Project

- **The purpose of the Athens Automation Control Experiment was to develop and test:**
  - **load control options,**
  - **voltage and reactive power control options,**
  - **distribution system reconfiguration capabilities**

  on an electric distribution system from the transmission substation transformer to individual residential appliances.

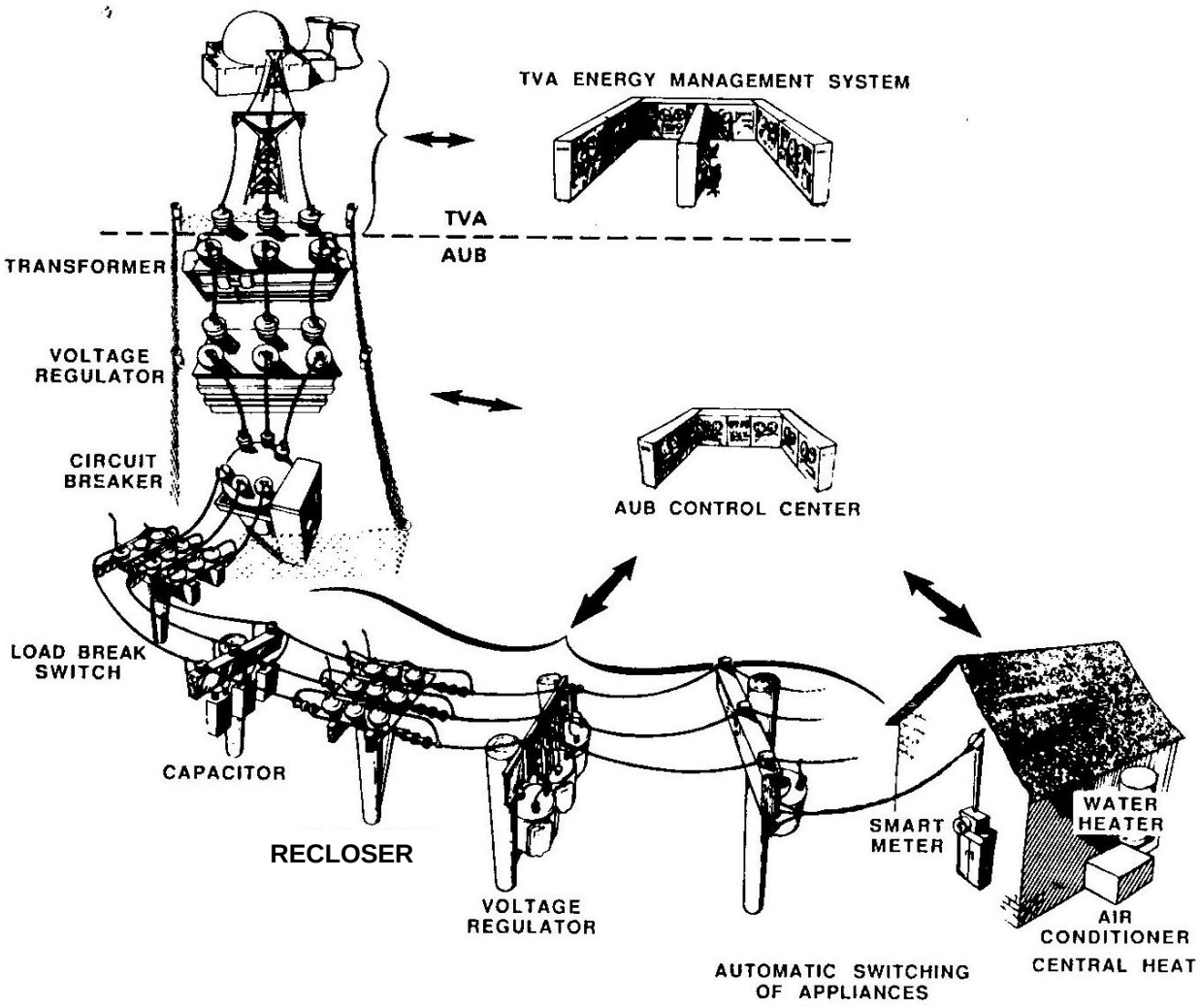


Figure 1-1 Automated equipment for the Athens Automation and Control Experiment.

Improving Grid Reliability through Distributed Energy Systems

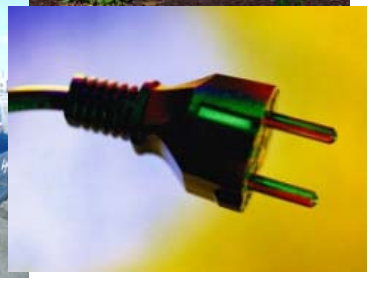
DECC Facility

- Unique facility for testing reactive power from distributed energy (DE) established in 2006
- Located on ORNL campus and interfaces with ORNL distribution system
- Developing controls for voltage and power factor regulation to improve system reliability
- Partnering with utilities and generation suppliers

Distributed Energy Communications and Controls (DECC) Facility can test inverter and rotating generation equipment

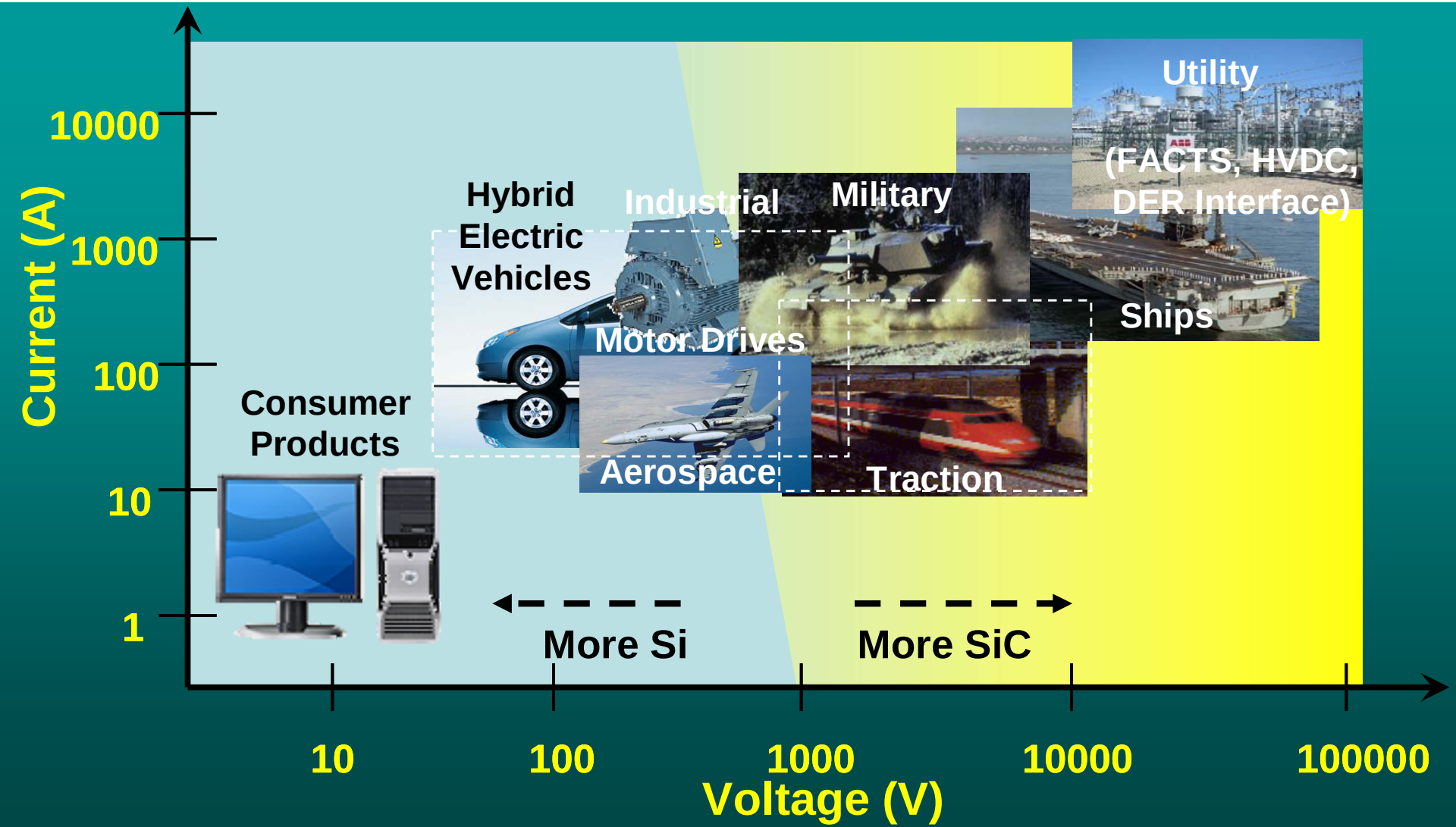
DECC Facility Plans

- Photovoltaic units to assess opportunity for reactive power compensation
- PHEV to study interface with grid
  - Charging while providing reactive power
  - Ancillary Services



Power Electronics are an enabling technology for modernizing the electric grid

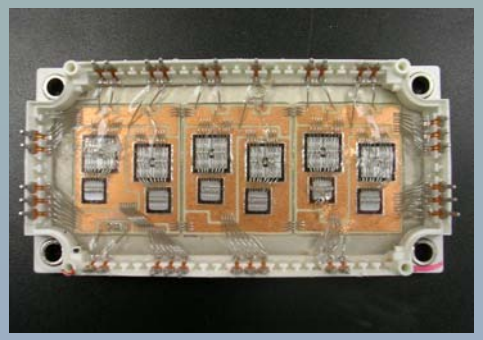
Utility-Scale Power Electronics Have Unique Challenges

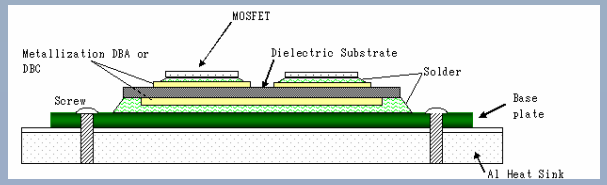


ORNL has expertise in power electronics development

Power electronics for two-way power flow control (reliable and low-cost)

Advancements in High Temperature Packaging and Thermal Management





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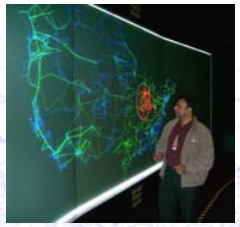
Electric Grid R&D Program at ORNL

Visualization & Controls

ORNL R&D Computational Techniques for Electric Delivery Systems R&D

- **Wide-area visualization**
- **Spatio-temporal representation**



Decision Support

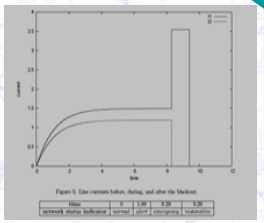
Simulation-based discovery

Scenario-steering

User-discovery

Application scenarios: grid-state, outages

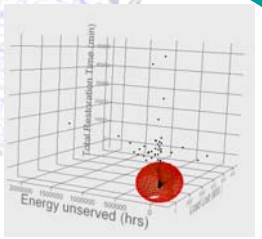
Modeling and Simulation



Algorithm parameters

Specifications

Data-analysis



- **Hybrid simulation**
- **Parallel contingency evaluation**

- **Distributed control and communication**
- **Data-directed discovery**

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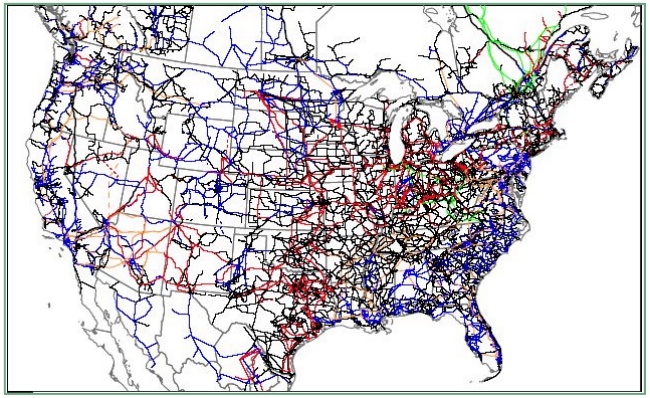
ORNL Simulation and Modeling

- **ORNL-led team selected to build the National Leadership-class Computing Facility**
- **Cray X1 evaluation completed**
  - **Expanded from 256 to 512 processors**
  - **Global ocean simulation: 50% higher simulation throughput than on Japanese Earth Simulator for equal number of processors**
- **Plan is to increase capability to 1 petaflop (1,000 trillion calculations per sec)**
- **Research Areas include:**
  - **astrophysics - supernova research**
  - **climate and carbon research- climate simulation**
  - **computational biology**
  - **fusion simulation - plasma energy research**
  - **industrial innovation - combustion simulation**
  - **materials research - precise calculations of molecular structures**
  - **nanomaterials theory**

Xtreme Power Systems Analysis (XPSA)

Demonstrate the use of high performance computing with standard industry software to perform full-systems analysis for utility planning studies, with implications for near-real time analysis on a scale previously not accessible to the utility industry.

- **Working with TVA system planning engineers**
  - **Provided a test case of the TVA electric grid**
  - **Typical solution time benchmark of 5-10 hrs**
- **Using power industry standard analysis code (PSS/E), specially converted use on the ORNL Institutional Cluster (OIC)**
- **Initial results:**
  - **One processor completed analysis in 2 hrs**
  - **128 OIC processors in 10 seconds**
- **The next phase of the project will demonstrate double-contingency (N-2)**
  - **TVA estimates it would take two years with existing serial processing capability**
  - **ORNL anticipates the same calculation can be performed under 168 hours**



Regulation from Industrial Loads

Problem Statement

- Generation reserves held back to compensate for minute-to-minute load fluctuations
- Energy & economic inefficiencies are significant (0.4 quads & $4Billion)
- Arc furnace loads will place additional burden on the TVA region
- Additionally the nation is losing aluminum manufacturing capability
    - Energy is ~30% costs of Al production
    - 43% of capacity shut down in 2001, in part, due to high energy prices

Benefits to Al Industry

- Plants, such as Alcoa's Massena facility, could earn $14M/yr if 10% of load is used for regulation

Problem Solution

- Large loads have the ability to help balance generation and loads (regulation)
- Electrolytic processes, such as aluminum, provide over 14,000 MW of regulation
- Regulation is the most expensive ancillary service by 5-8x spinning reserve
- This could benefit aluminum industry and grid security in near term:
    - Maintain smelting operations & jobs in the U.S.

Electric Grid Analysis & Situational Awareness

- Major power outages over the past decade have occurred due to a lack of wide-area situational understanding
- ORNL, in partnership with TVA, is developing real-time status of the electric grid and assess inter-dependencies with critical energy infrastructure
- Assist in coordination of federal response to natural disasters or major events

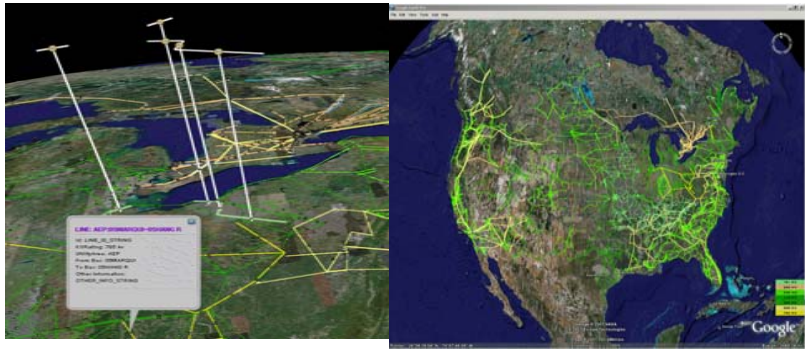
VERDE

Visualizing Energy Resources Dynamically on Earth

VERDE Capabilities

Visualizing Energy Resources Dynamically on Earth

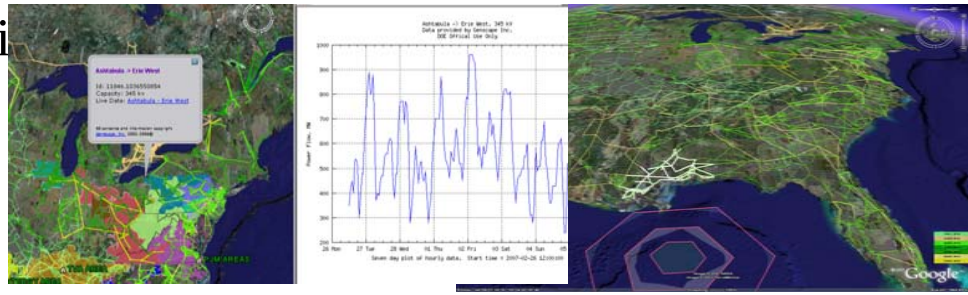
- Platform provides wide area visualization capability
  - Flexible system
- Real-time status of transmission lines
- Real-time weather overlays
- Predictive impact models & Animated replay
- Data analysis
- Energy infrastructure interdependenci
  - Coal delivery and rail lines
  - Refinery and oil wells
  - Natural gas pipelines
  - Transportation and evacuation routes
  - Population impacts - LandScan

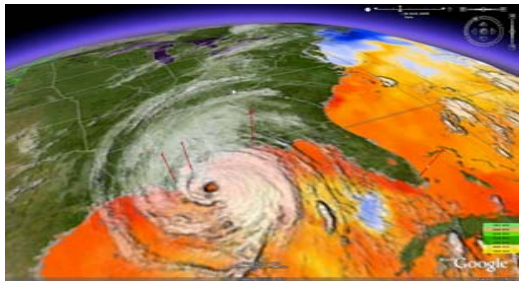


Wide-Area Power Grid Situational Awareness

Streaming Analysis

Impact Models





Real-time Weather Overlays

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Electric Grid R&D Program at ORNL

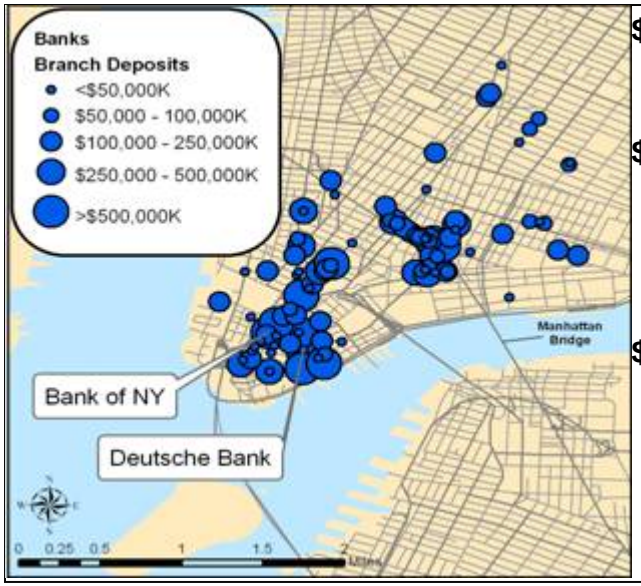
Department of Homeland Security's
Resilient Electric Grid

OAK RIDGE National Laboratory

Homeland Innovative Prototype Solution
Resilient Electric Grid (REG)

Problem:

- US electrical grid is subject to black outs, brown outs, rolling outages, and cascading failures; Annual loss in the US from power outages and fluctuations at $1B annually to NYC and $100 billion nationwide.
- Loss of power in lower Manhattan disrupts entire U.S. banking transactions capability. E.g. ~ $100 B per day Fed Funds trading in Manhattan.
- Coupled with terrorist acts, this vulnerability could result in cascading electrical outages with $Trillions of potential damage and devastating effect on the US economy.



$ 100B/day in federal funds trades

$1B/year in losses to "normal" electrical failures

$750M in losses from 1 outage (2003)

Proposed Solution:

- High Temperature Superconductor (HTS) cables and HTS fault current limiters (FCL) between substations in the Manhattan power grid allowing Area Substations to share excess capacity in emergencies
- Technology Demonstration by FY08
- Integrated System Test and Demonstration by FY09
- Transition in FY10

Payoff:

- Foundation for a resilient electrical grid demonstrated in the existing grid – immediately transitionable to other critical infrastructure
- Fully deployed, it could save $100B/year in losses to normal events (~$1B/year in NYC)
- Potential to prevent devastating ($Trillions) impacts from terrorist attacks

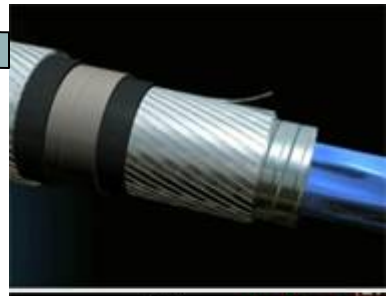
Homeland Security

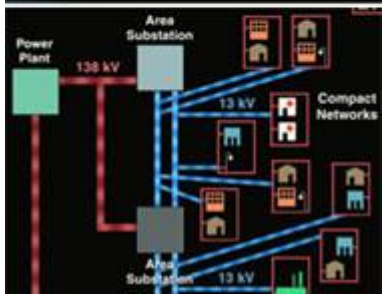
OAK RIDGE National Laboratory

DHS Resilient Electric Grid

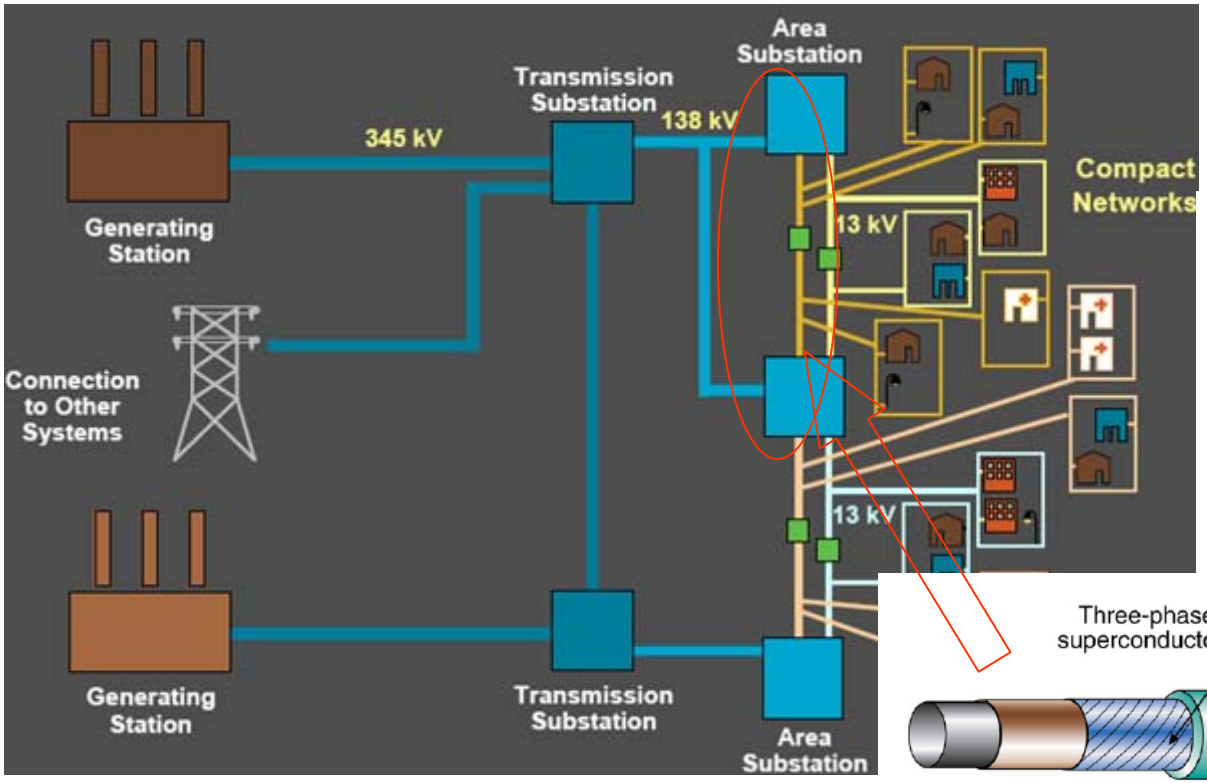
- Department of Homeland Security and ConEd investing $39 million over the next three years to connect two substations, for system redundancy
- Protect against natural disruptions and terrorist attacks.
- Superconducting cables offers unique advantages
  - Far more compact than copper wires.
  - Surge protection can be engineered directly into the cables due to their inherent nature
- Concept will be proved by August 2008. Actual construction in 2010.
  - Design, build , develop testing protocols, full prototype tests, analyze data, develop a design specification for installation
- ORNL will provide testing of 3 m cable and designated as the subject matter experts

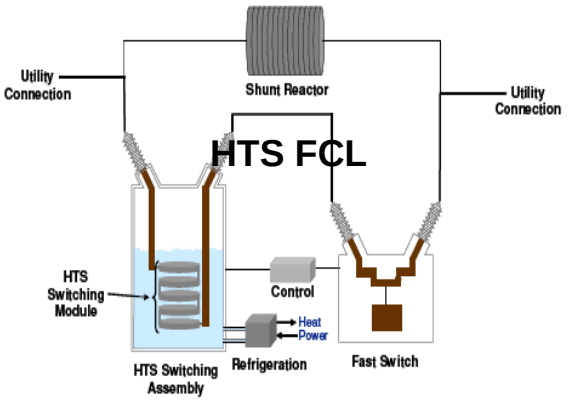
William Street & Fulton Street, NY City (2003)

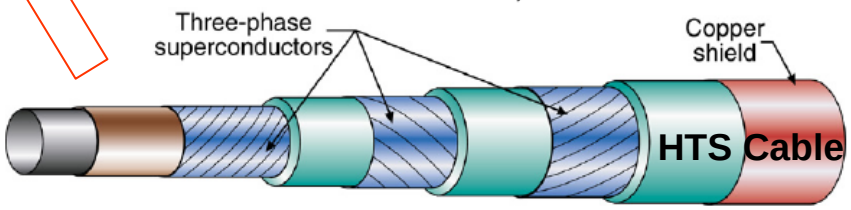




REG and High Temperature (HTS) Superconducting Cables







- HTS Cable linking substations in the grid allows area substations to share excess capacity in emergencies
  - w/o HTS, there just isn't real estate under urban areas – copper is just too big
- HTS FCL allows the two substations to be continuously connected under normal and contingency conditions and to limit current flow between substations during fault conditions
  - w/o FCL, linking the substations could generate dangers short circuit "fault currents"
  - w/o HTS FCL, there would be excessive resistive and inductive losses on the line


OAK
RIDGE
National Laboratory