Smarter Energy for a Smarter Planet: Computational Challenges and Dependencies of the Evolving Smart Grid

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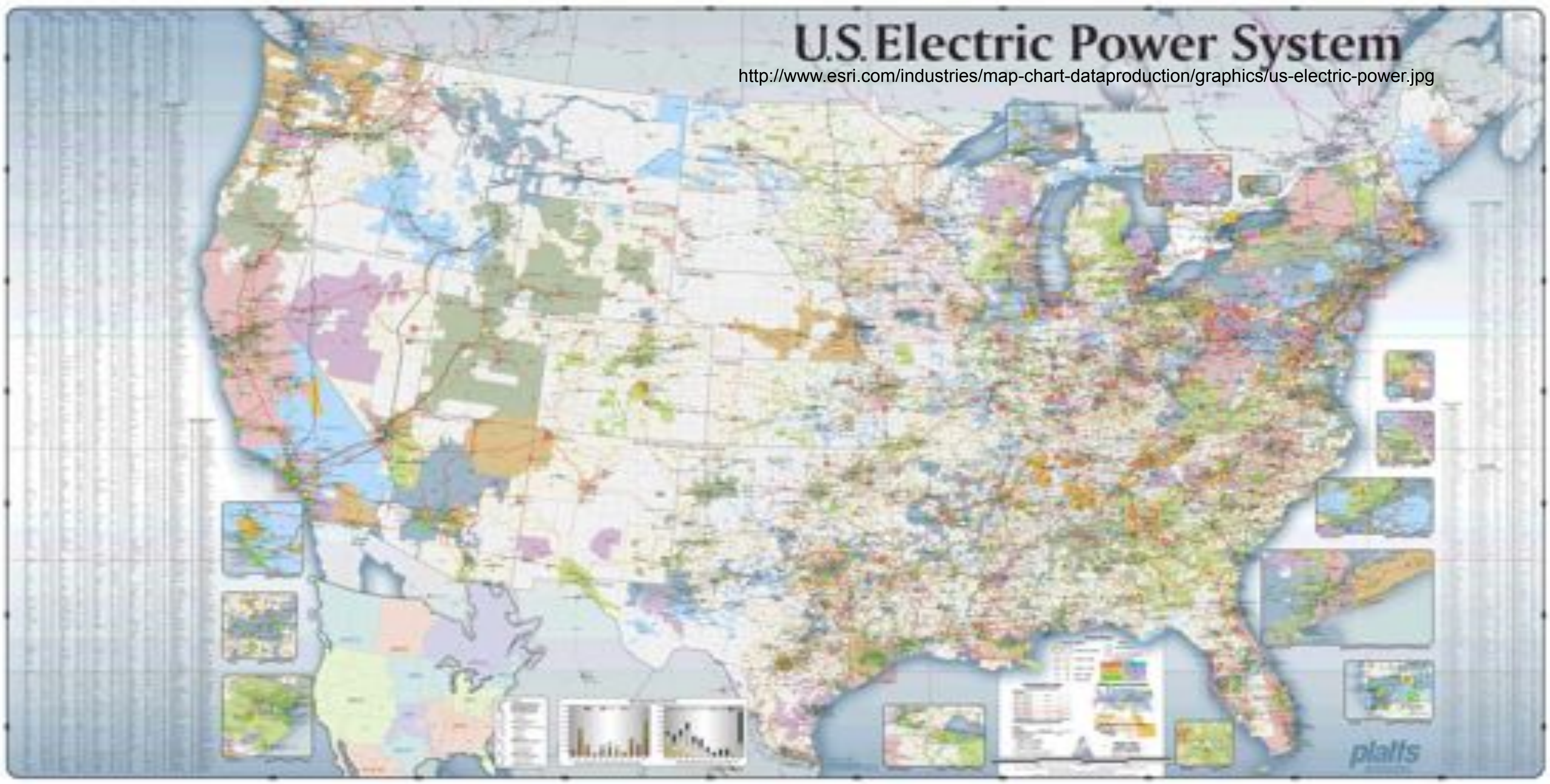
IBM

US Electric Grid – "Incredibly Complex"

- ~3300 Utilities, 15,000 generators, 211,000 mi of high voltage T-lines (>230 kV)
- In 2008, the installed generating capacity in the United States was 1,048,313 MW
- According to the EIA, 281 GW of new generating capacity will be needed by 2025

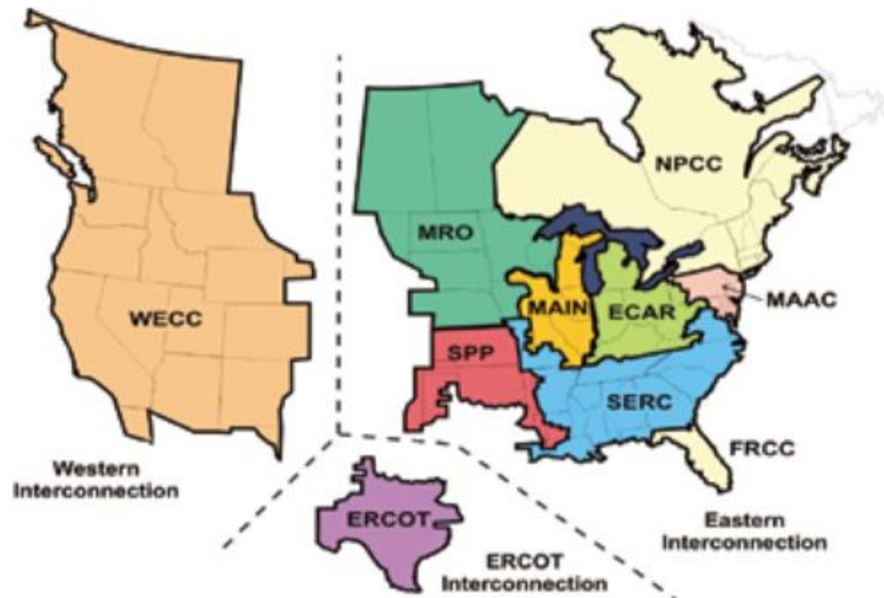


http://www.esri.com/industries/map-chart-dataproduction/graphics/us-electric-power.jpg

US Electric Grid Breakdown

- Grid reliability is managed by FERC http://www.ferc.gov/ NERC http://www.nerc.com/
- 3 Regional interconnects WECC, Eastern and ERCOT
- 8 Reliability Coordinating Councils
- ISO’sRTO’s, Utilities…

http://www.isa.org/Images/InTech/2009/April/USmap.jpg



http://www.geni.org/globalenergy/library/articles-renewable-energy-transmission/graphics/NERC_Interconnections_color.jpg

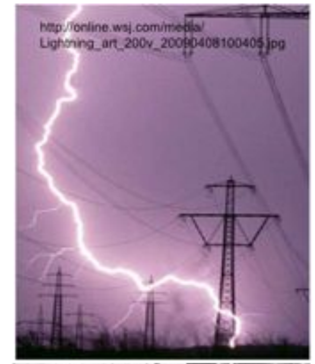
The three grid interconnections in North America. : ECAR, East Central Area Reliability Coordination Agreement; ERCOT, Electric Reliability Council of Texas; FRCC, Florida Reliability Coordination Council; MAAC, Mid-Atlantic Area Council; MAIN, Mid- America Interpool Network; MRO, Midwest Reliability Organization; NPCC, Northeast Power Coordinating Council; SERC, Southeastern Electric Reliability Council; SPP, Southwest Power Pool; WECC, Western Electricity Coordinating Council.

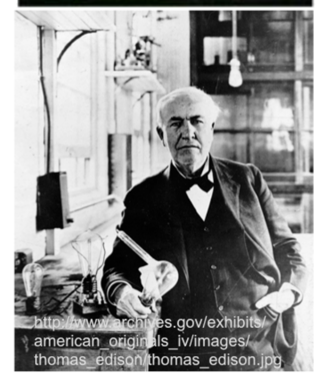
Major electric grid challenges facing the nation & world today

- **Aging limited infrastructure** to capacity constraints as demand continues to grow, about 25% since 1990, while construction decreased by ~30%[1].

- **Heterogeneous** mix of equipment that dates back to the 1880's and the days of Edison, but it is also the heart of much of the critical U.S. infrastructure of not only energy, but communications, transportation, water and more.

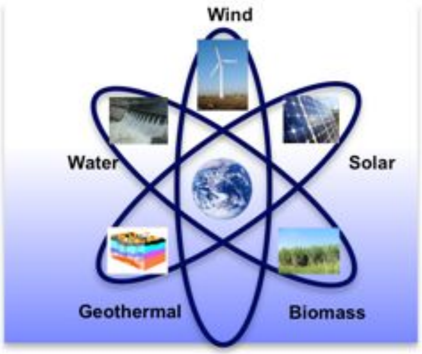
- The transmission system represents over 211,000 miles of high voltage transmission lines (>230kV) with **limited growth due to physical and societal constraints**. Likewise the distribution system and even consumer side management have only seen limited upgrades.





Complexity vs. Need vs. Cost

- "The American electric grid is an engineering marvel, arguably the **single largest and most complex machine in the world**[1]."
- To continue growth we have to cut carbon, and increase renewables, DER… in other words significantly increase complexity.
- The idea of building a connected **"smart" grid that can route power intelligently** is beyond daunting…
- To do so will require us to reinvent how we **model, analyze, simulate & optimize** electric grid resources, management, planning and operations.
- It skirts closer to the edge of stability and reliability, with power interruptions and blackouts that cost >**$150 billion a year**[1].



1 - http://www.popsci.com/environment/article/2009-06/next-grid

Skirting closer to the edge: Major Blackout Examples

- November 9, 1965: an outage, affected **30 million** people over an area of 207,000 km^2 (about 80 000 mi^2) from eastern Ontario through New York State and much of New England for periods ranging from a few minutes to 13 hours.
  Cause: A **faulty relay** at a power plant in Ontario

- July 14, 1977:Widespread power outages in New York City and Westchester County. Electric service to more than **8 million** people in the New York metropolitan area and to the commercial and industrial users in this area was interrupted from 5 to 25 hours.
  Cause: A **lightning strike**

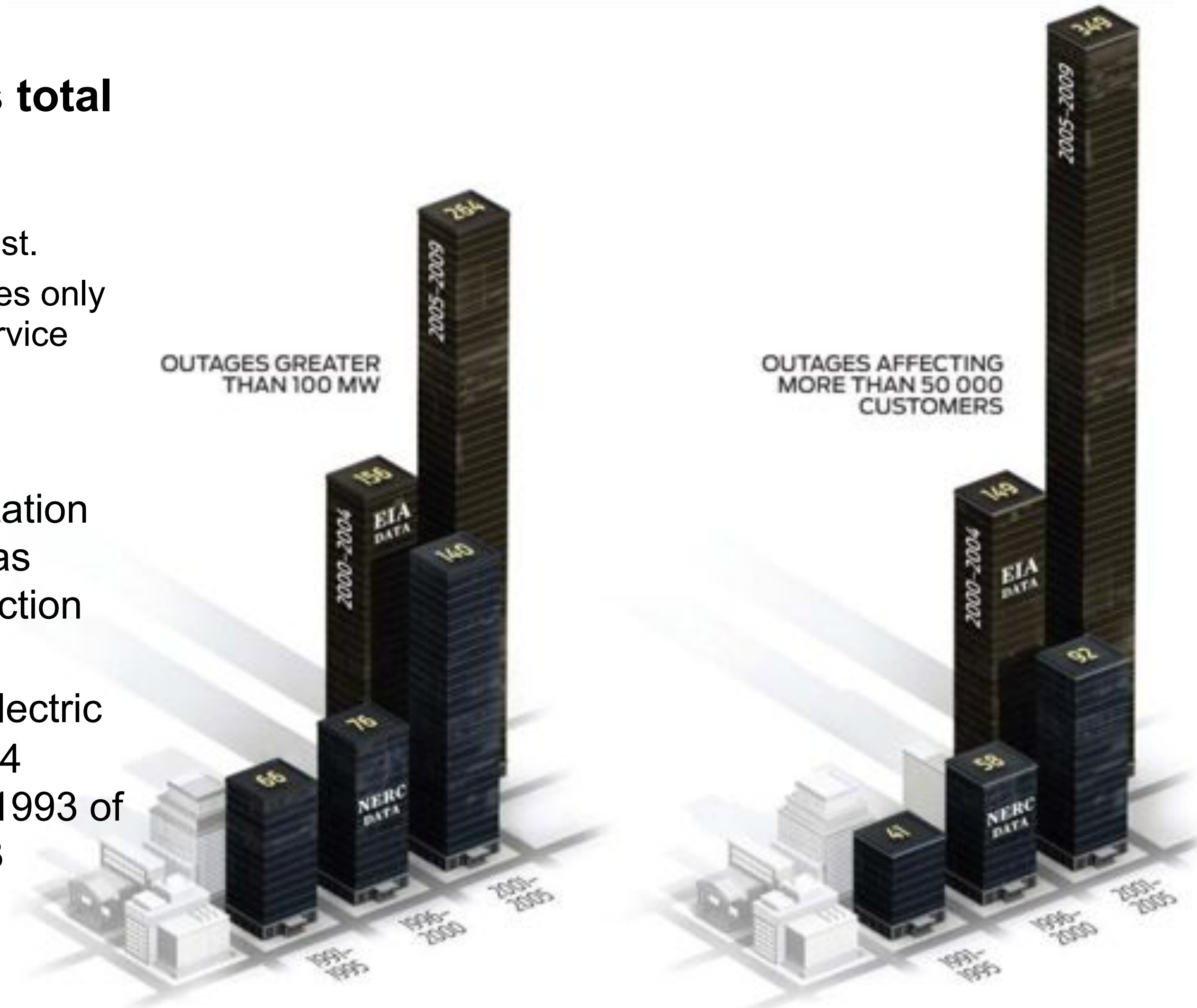
- August 14, 2003:North American power grid experiences its largest blackout ever. Affects **50 million** people, more than 70,000 megawatts (MW) of electrical load in parts of Ohio, Michigan, New York, Pennsylvania, New Jersey, Connecticut, Massachusetts, Vermont, as well as Ontario and Québec for 2-7days
  Cause: **Untrimmed trees** and a SW Bug. https://reports.energy.gov/


The New York Times.
LATE CITY EDITION
POWER FAILURE SNARLS NORTHEAST; 800,000 ARE CAUGHT IN SUBWAYS HERE; AUTOS TIED UP, CITY GROPES IN DARK
To Our Readers
Johnson Restates Goals in Vietnam
Snarl at Rush Hour Spreads Into 9 States

http://theenergylibrary.com/node/647

US Electrical Grid Outages are Getting Progressively Worse

- **Yearly average outages total**
  - 92 minutes per year in the Midwest and
  - 214 minutes in the Northeast.
  - Japan, by contrast, averages only 4 minutes of interrupted service each year.
- **What happened?**
  - Since 1995, the amortization and depreciation rate has exceeded utility construction expenditures
  - R&D spending for the electric power sector dropped 74 percent, from a high in 1993 of US $741 million to $193 million in 2000



Data sources: NERC & EIA

U.S. Electrical Grid Gets Less Reliable By S. M. Amin / January 2011
http://spectrum.ieee.org/energy/policy/us-electrical-grid-gets-less-reliable

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…Where a transformed grid will re-shape value chains, empower consumers & provide energy for a sustainable future

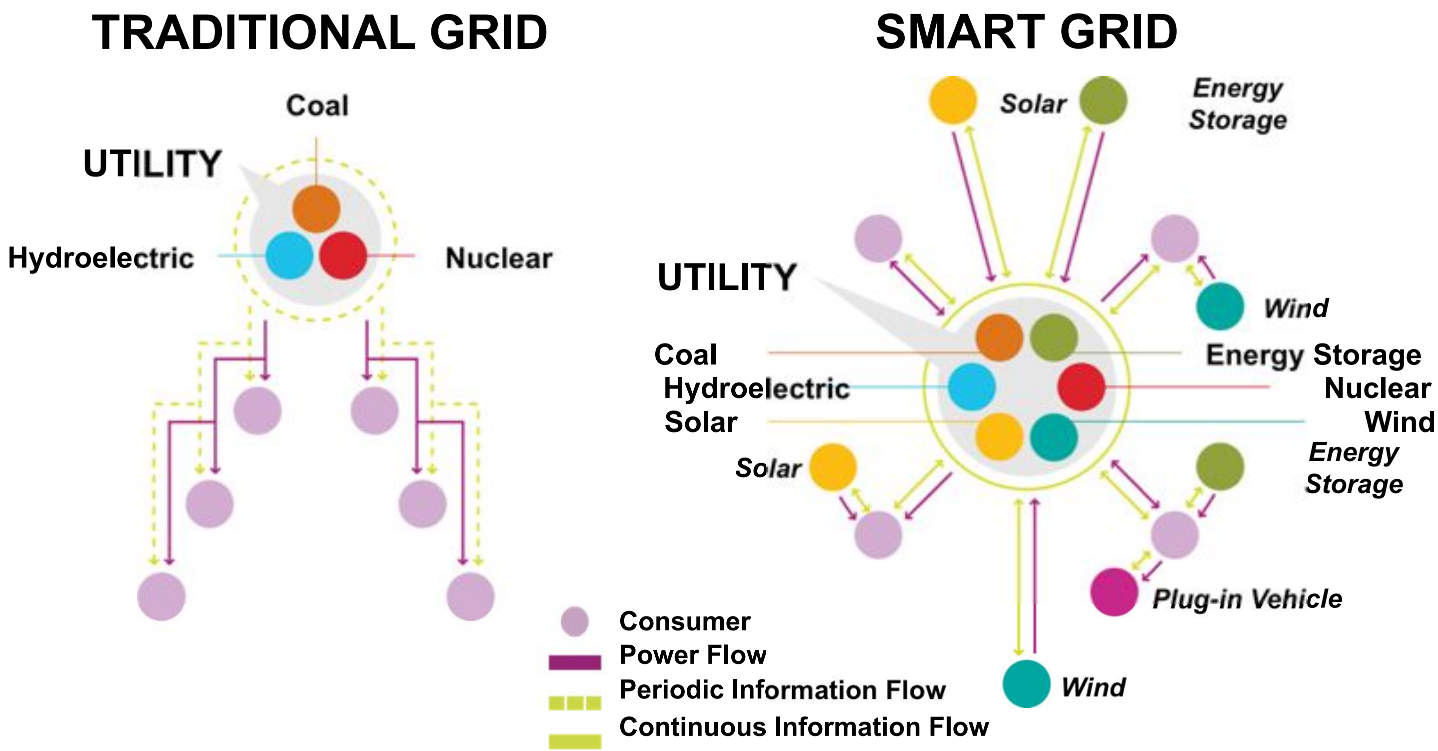
Informed

Automated

Integrated

Connected

Intelligent



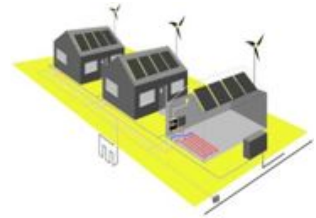
- Grid is becoming bi-directional, fully Instrumented, interconnected and a hierarchically distributed complex system of systems.
- Data (PMU's, Meters, IEDs, SCADA, EMS, DMS...) is becoming Is massive, bidirectional with timescales shifting to be more real-time.

Smart Grid Features as Defined by NIST/EPRI *

- **Self Healing**
  - Identifies and reacts to system disturbances and performs mitigation efforts to correct them. Allows problems to be isolated, analyzed and restored with little human interaction
- **Active Customer Participation**
  - Motivates and includes customers including them as a component of the overall system enabling them to make decisions which will drive new technologies and markets
- **Resilient to Man Caused and Natural Disasters and Cyber-Attacks**
  - Resists attacks on physical infrastructure and cyber-structure (markets. systems, software and communications)
- **Enhanced Power Quality and Reliability for 21st Century Loads**
  - Provides reliable power which is interruption-free
- **Support of All Generation and Storage Options**
  - Accommodates all generation and storage options
- **Enables New Products, Services and Markets**
  - Provides a market system which enables cost-benefit trade-offs to consumers by creating opportunities for providers to bid on services
- **Asset Utilization and Operational Efficiency**
  - Assets work with each other to optimize operational efficiency and reduce costs

***NIST/EPRI Modern Grid Initiative**

Challenges of the Evolving Smart Grid



- Renewable Portfolio Standards (RPS) mandates or **renewables (e.g. wind, solar) from the ~1% today to 20-30%** by 2025, while *managing intermittency*.
- Eroding transmission capacity margin and investment in transmission infrastructure has lagged the growth in demand, yet **long haul transport is needed for renewables**.

- **Plug-in electric vehicles**, battery storage devices and smart appliances can fundamentally transform our energy, but need to be *quantified, managed & leveraged.*

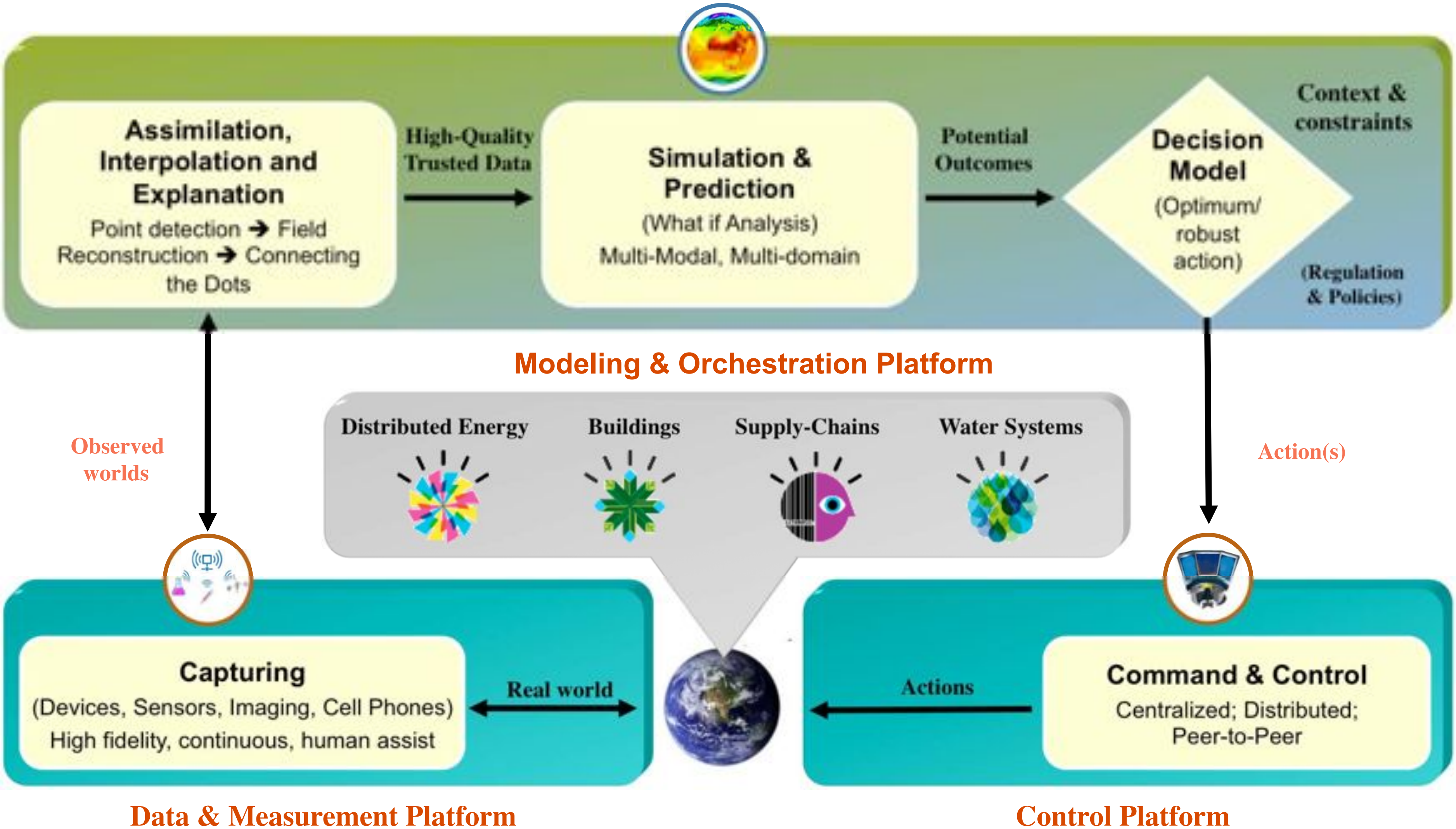
- **New sensing technologies** enable *real-time information, analysis, and control capabilities*, to be more observable, controllable, and automated for example:
  - PMU's Phasor measurement units synchronized by GPS signals collect and report dynamic data.
  - FACTS devices, Intelligent Electronic Devices (IEDs) and sensors for observation and control of power flow.
  - Hundreds of millions of smart meters are being deployed to enable load response.
- **Real-time energy markets** require new more comprehensive, integrated and faster tools to ensure safe, fair and effective *real-time operation*.

- With **smart grid communications**, observability and controllability come the need to develop effective *cyber-physical security*.
- **Government oversight** driving the need *to monitor, optimize and control* carbon generation and emissions across this mix of new capabilities and options

Contents

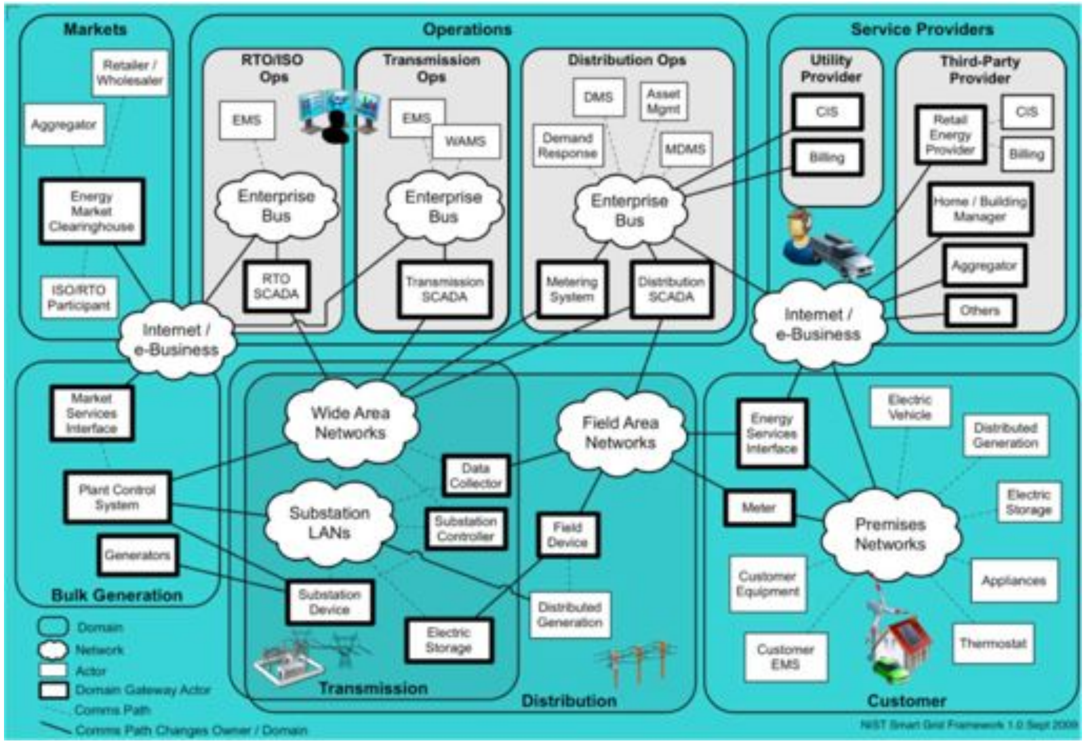
- Today's Grid
- The evolving smart grid
- Smarter Energy research

Interconnected and interdependent behavioral models will provide the intelligence to predict outcomes and exercise closed loop control



The Grid is an Ultra Large-Scale Complex Systems of Systems

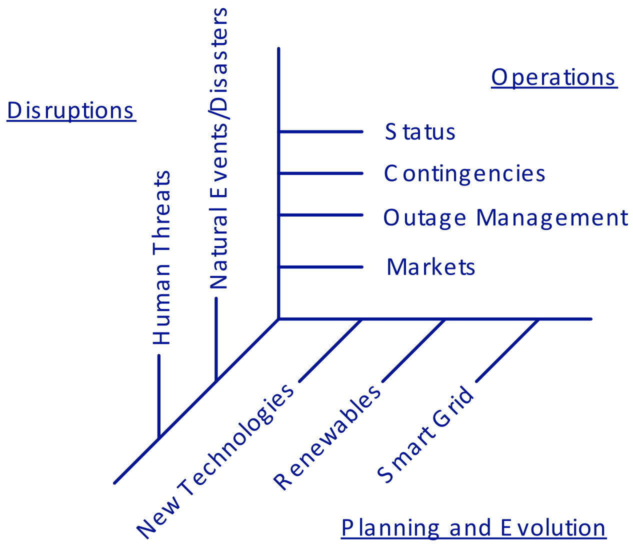
- **Smart grids are complex *systems of systems* that must integrate and interoperate across a broad spectrum of heterogeneous business and operations domains**
  - Involves multiple enterprises and customers in multiple industries
  - A loosely-coupled distributed system approach is required
  - Application-level interoperability standards are critical to success
  - Ultimately, we want to enable global optimization that achieves continual balance across the many constraints involved



It's a data driven world…

Smart Grid Computational Situation

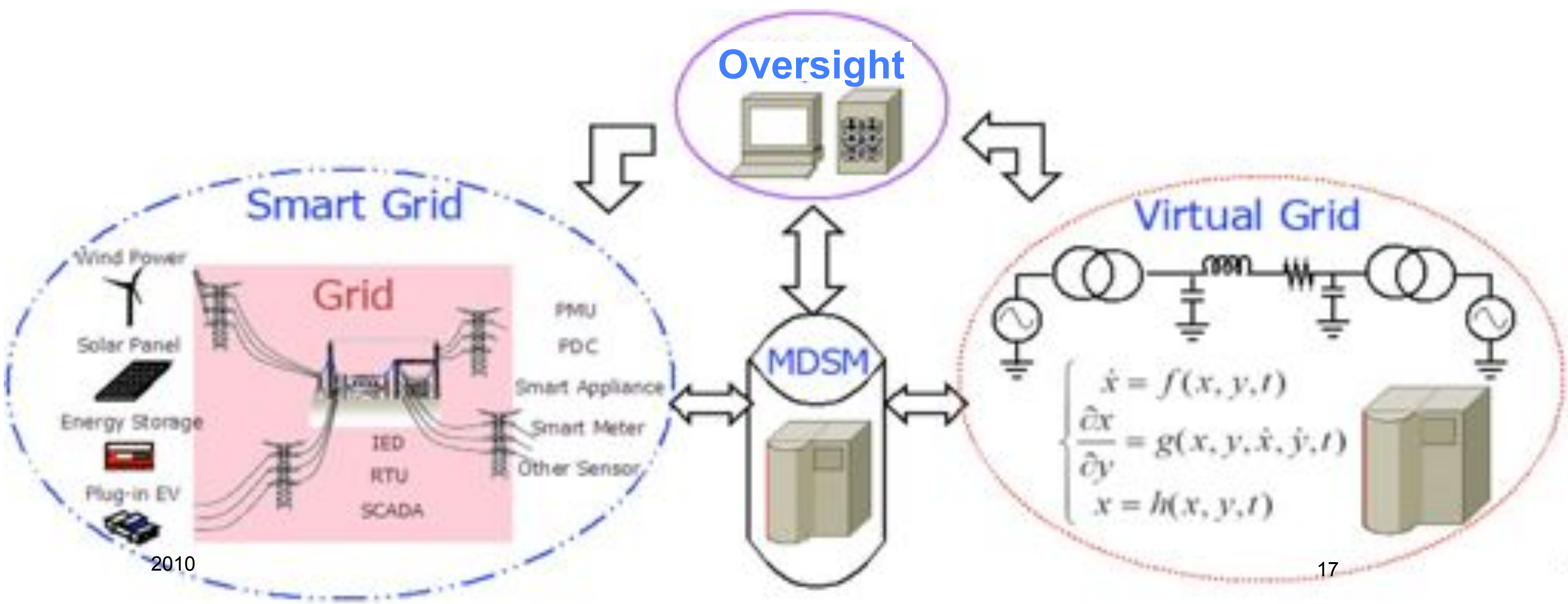
- **The smart grid drives the need for dynamic, real-time simulation and analytics – from generation through distribution across multiple dimensions**
  - 100's of millions of nodes, each a set of ODE's
  - Time-scale: 120Hz data, 10's of mins to hours,
  - Data-scale: Tbytes of streaming data/day
  - Event Horizon: ~1 sec to detect anomaly, create remedial action and implement. Events travel ~600Miles/sec
- **Development of hybrid supercomputer systems, streams, data mining and analytics, integration of broadly distributed sensor networks, and real-time visualization**
  - Including demand modeling and environmental influences



Hybrid Supercomputer System

Data Driven Computational Changes

- The systems and data need to be analyzed together and in whole new ways.
- Cross domain optimization, including uncertainty and with some in near real-time.
- Existing and new data mining techniques need to be brought to bare in energy industry.
- New approaches are needed to solving the math to meet the constraints & time scales
- New data management is needed; from acquisition, compression, usage, mining, patterns, anomaly detection, prediction...
- New dynamic modeling needs to be developed for the power industry for stability analysis, state estimation, ...
- Secure, reliable efficient systems, will require broad, deep and 'real-time' oversight, w/ feedback control
- Storage is a key to integration and use of DER, but it is expensive and difficult, to be balanced with analytics.
- Move from reactionary to more proscriptive, via a 'virtual power grid' based on state estimation.
- New visualization is needed to enable operators 'easy' Situational Awareness and intuitively act upon events.
- Ultimately the industry will need to move toward more fully automated systems that fit the shrinking timescales
- This all circles back to the underlying math, algorithms, platforms and hardware that will be needed across the diverse, but interdependent stakeholders.



Vision & Value Proposition

- The Energy and Utilities industry is in the midst of a **transformation**. Access to the best **research and innovations** will be key factors in determining its **success.**

- IBM's Point of View is that **Analytics, Modeling, Simulation, Optimization and Advanced Computing** will be central to value creation for many years to come.

- IBM is committed to delivering these capabilities to the industry through the creation of a **Smarter Energy Platform** that will provide:

  - **An integrated and scalable HW/SW infrastructure** optimized for analytics, modeling, simulation and optimization applications and services of relevance to the E&U industry.

  - **A portfolio of analytics-based applications and services** and a commitment to build an industry-leading **developer and partner ecosystem.**

  - Centralized and decentralized **Informed Decision Making** throughout the enterprise driven by **Model-Driven Control Centers** and distributed **Smarter Energy Terminals**.

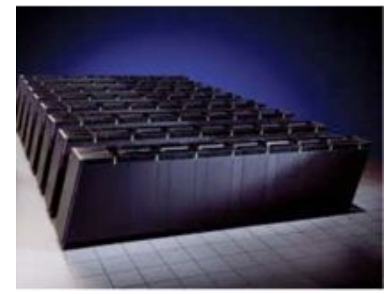
Informed Decision Making in E&U….What if?

Appliance@Utility

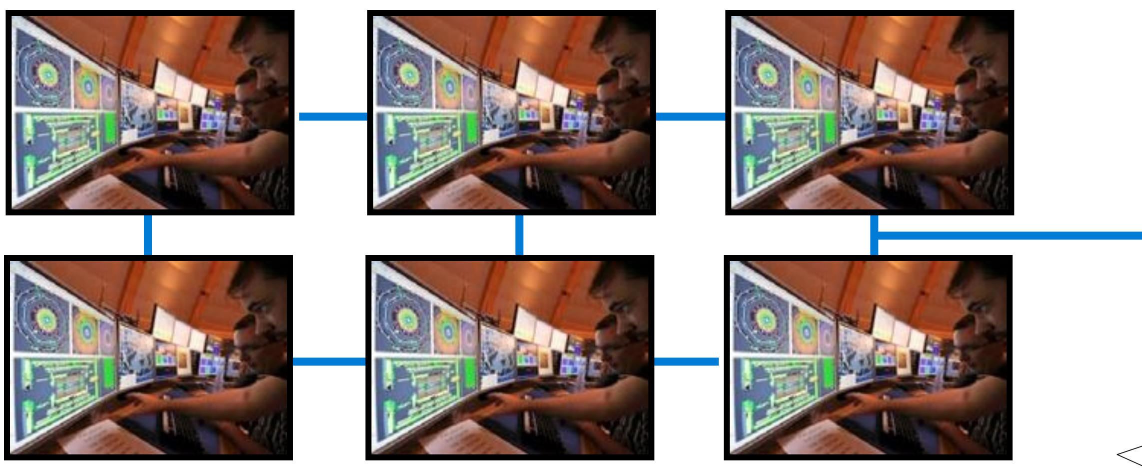
Hosted Service via
Smarter Energy Cloud

Smarter
Energy
Platform

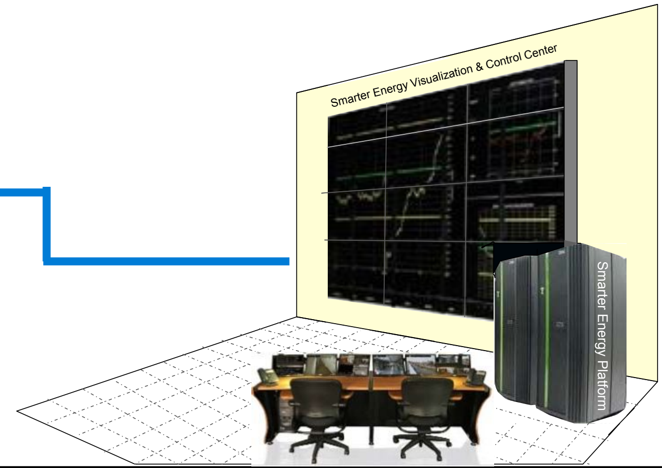
HPC



Developer & User SEP Terminals



Model Driven
Control Center



Improving the Consumability of Analytics
Informed Decision Making in the Financial Industry
Case Study: Bloomberg LP

Bloomberg provides a service that bundles news, with financial data and analytics in real time. It is delivered over its ~300,000 terminals.

Bloomberg is planning to expand into providing analytics for the government sector

The Importance of Model-Driven Control Centers

Control Center of Renewable Energies

REE, Madrid (Spain)

Real Time Crime Center

NYPD, New York (USA)

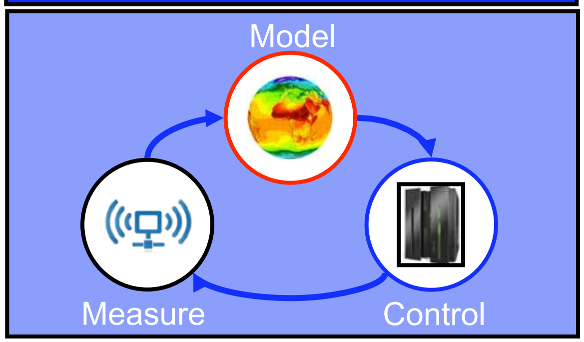
Traffic Control Center

Florida Department of Transportation (USA)

Disease Control Emergency Ops Center

CDC, Atlanta (USA)

Model-Driven Control Centers



Oil Control Center

MERO Middle European Raw Oil (Czech Rep)

Water Control Center

The Athens Water Supply & Sewerage Co.
Athens, Greece

Fire Prevention Bureau

Fukuaka City (Japan)

Global Network Operations

AT&T, New Jersey (USA)

Smarter Energy - model-driven optimization enables substantial electricity (>20%) generated through renewable energy

Management of intermittent energy generation

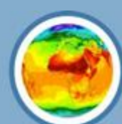
Real-time model-driven control framework to manage and integrate renewable energy into the grid infrastructure

Predictable Generators

Spain's Electrical Grid
Incorporates 20% of Intermittent Energy

Smarter Planet Platforms


Data & Measurement


Model & Analytics Orchestration

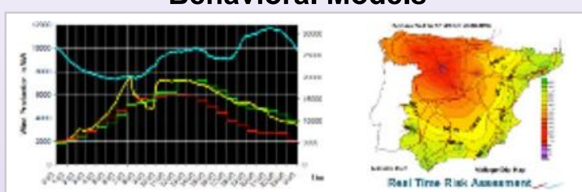

Control

Results

Real-Time Visibility

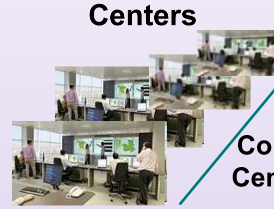
Country-Wide Measurements Every 12 secs
Active & Reactive Power
Voltage & Connectivity,
Temperature, Wind Speed

Behavioral Models



Real Time Modeling & Risk Assessment
Data Models & Assimilation
Weather Models
Wind and Solar Forecast
Consumption Forecast

Interconnected Control Centers



30+ Control Centers

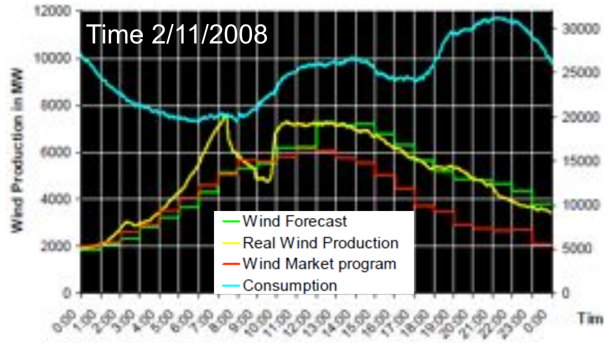
Management & Control
Optimal Unit Commitment
Supervision & Control of
Energy Generators

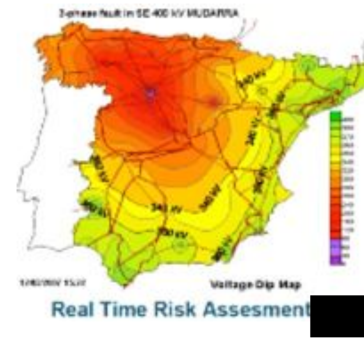
Control Center of Renewable Energies

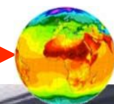
Modeling & Simulation

Data Models & Assimilation
Weather Models
Wind and Solar Forecast
Consumption Forecast

Scenario Generation & Real-time Risk Assessment







Country-Wide Measurements Every 12 secs

Active and Reactive Power
Voltage
Connectivity
Temperature
Wind Speed/Weather

Control Center of Renewable Energies

24/7, 365 days
Full redundancy
Regulation Compliance
Reliability
Predictability
Production Maximization
Security

Real-Time Mgmt & Control

Optimal Unit Commitment
Supervision & Control of
Energy Generators

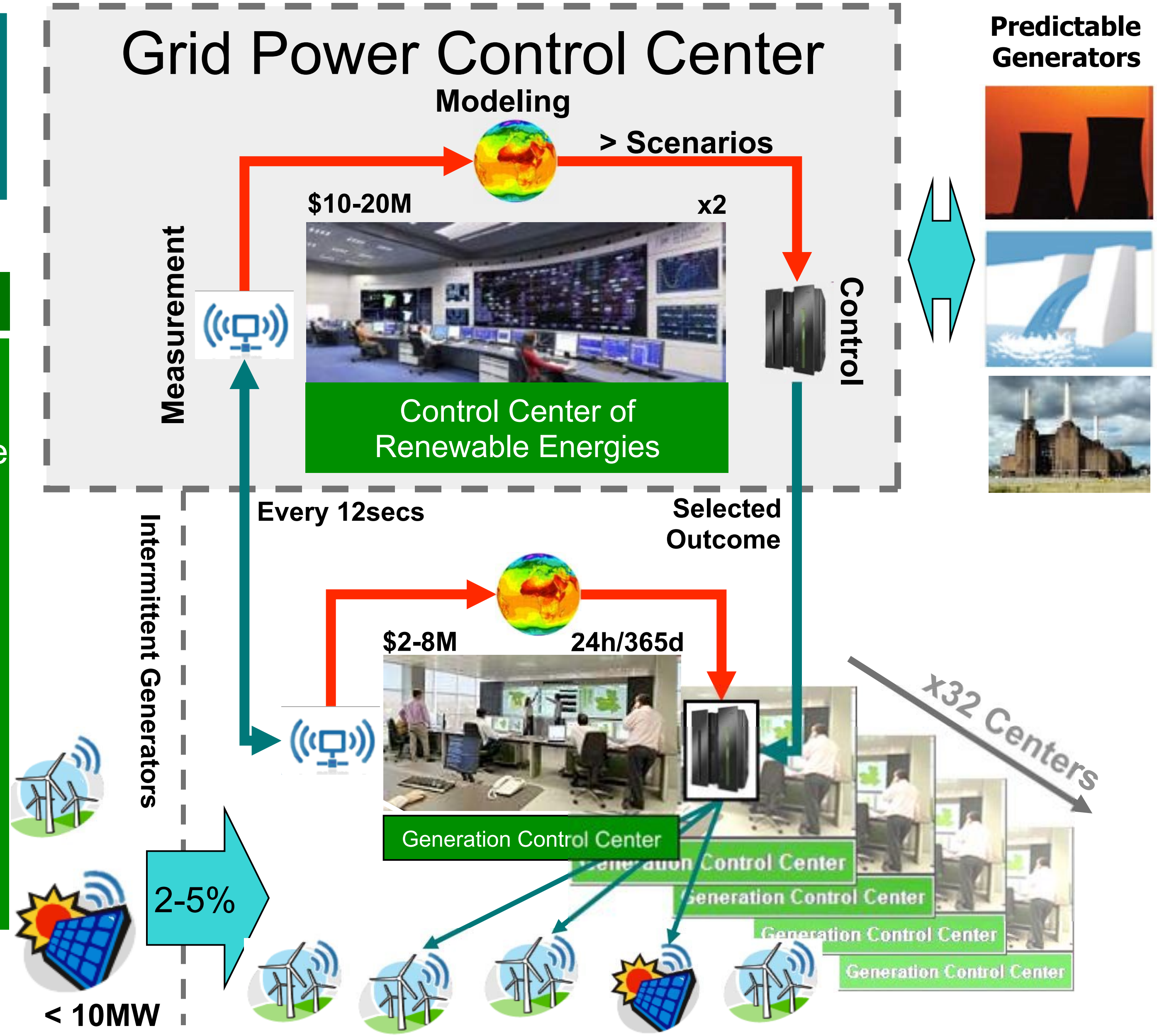
Real-World Example
Control Centers to Manage **Intermittent Energy** Generation

Spain – Case study

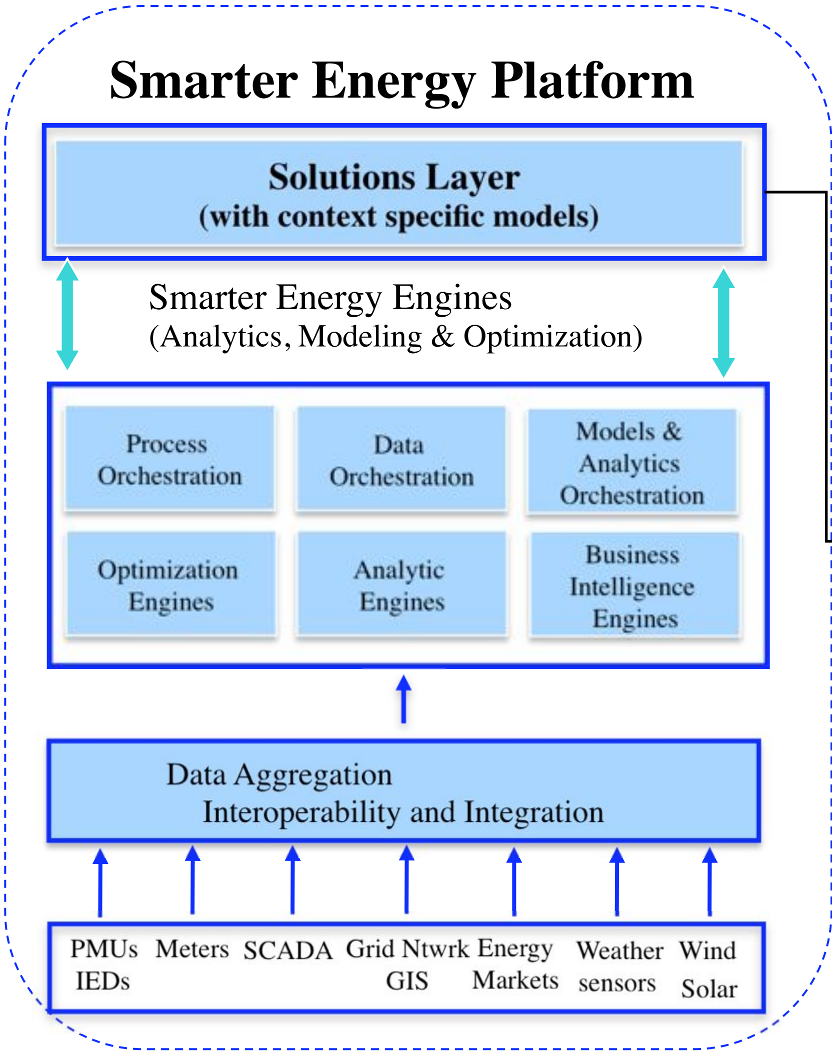
A world leader in installed renewable energies & infrastructure Wind & Solar

- **20% Today**
- **40% Target for 2020**

Implemented pioneering real-time model-driven control system to manage & integrate renewable energy into the grid infrastructure



The Smarter Energy Platform – A Single Platform Creating New Ecosystems Delivering Applications, Efficiencies & Services



Smarter Energy Applications

(examples of current IBM Research capabilities)

- Intermittent Renewable Power Forecasting (Wind & Solar)
- Integrated Distributed Outage Planner
- Intelligent Grid Assessment & Planning
- Phase Identification and Balancing
- Power Outage Prediction
- Transactive Control of Energy Delivery
- Condition Based Management
- Voltage stability monitoring
- Managing the Dispatch of Demand Response
- Building Energy Services
- Microgrid Design & Management
- Optimization of Electric Vehicle Charging Station

….and many other possible applications

Engines & Capabilities to Enable Smarter Energy Platform

Mixed Transmission & Distribution Analysis:

–Power flow/Load flow
–N-x contingency analysis
–Real-time transient and dynamic models and analysis
–Real-time dynamic models (GIS, Topo, PMU, IED, SCADA…)
–Remedial action, planning, restoration
–Load estimation and peak load management
–Energy management – DA, DR, load shedding, protection, storage
–Reliability – CAIDI, SAIDI, SAIF
–Optimization of switching plans, capacitor, protection, load flow
–Multiple spatial and temporal scales

Advanced wide-area situational awareness & control:

–Automated topological/system visualization,
–Decision analytics and support
–Predictive/Prescriptive analysis & support
–Real-time control of grid
Data/parameter identification, oversight
Cyber-physical security simulation
Fault detection and isolation
Weather/Climate/Carbon integration
Multiple physics effects

Business, training and operations:

–Rate case analysis/structure analysis vs. customer adoption
–Cost/benefit/interaction of DER tech & new Tech
–End-user benefits/incentives
–AMI, DA, DR
–Wholesale/retail energy markets
–Grid assessment, analysis, planning & growth

Capabilities & Ecosystem to Enable

- Smarter Energy Platform Appliances, Cloud Services & Terminals
- Model Driven Control Centers
- A portfolio of energy analytics applications that could run on the Smarter Energy Platform with demonstrated customer value
- An ecosystem of developers and partners committed to develop energy analytics applications on our platform.

Huge Benefits with Complex Systems of Systems Simulations

Industry benefits

- Potential prevention of cascading failures (Save $100’s billions yearly)
- Dramatically increased penetration of renewables and DER (Greener planet…)
- Analysis of national concerns as consequences of regional events
- Minimize outages and costs
- Optimize interdependencies among critical infrastructures
- Perform operational and security tradeoffs
- Short- and long-term national planning and optimization of transmission and generation mixes with emphasis on increase renewables and DER
- Specific enhanced analytic capabilities
  - Advanced real-time N-x contingency and restoration analysis/remedial action planning
  - Real-time dynamic transient analysis
  - Parameter identification, model generation/verification
  - Event analysis and prediction across multiple spatio-temporal scales
  - Analysis supporting adaptive islanding
  - Grid simulation capability can be a key asset for building a hardware in the loop power-system hardware testing simulator of advanced power grid control algorithms

Can it be done?

What happens when the system fails?

- **What will it take to make such a complex and critical system reliable, available and secure?**
  - Systems have to be designed to account for inevitable failure and recovery
  - Hierarchical distributed nature needs to be developed and used.
  - Systems need to be semi-autonomous and capable of independent operation, but with feedback allowed.
  - Data needs to be managed in new ways
  - …

Should it be done?

Questions

- Thank you