A Smart Grid = A Software Grid

Computational challenges at peta-, exa-, and zetta-scales

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Outline

- Dynamical features of the power grid
  - Effects from millisecond to minute time scales
- Software features of the power grid
  - Communication and control
- Supercomputing applications
  - Challenges relevant today
  - Challenges for the next 2, 4, and 8 years
- Conclusions

Dynamics of the power grid

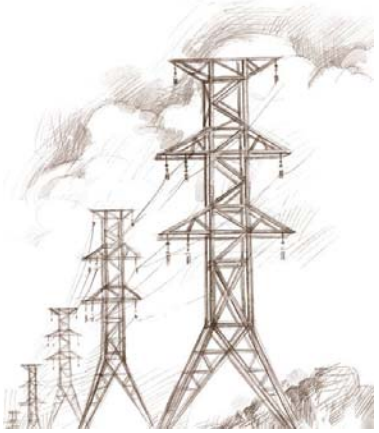
- The dynamics of modern power grids has four interacting components
- Physics dictates the
  - Mechanical
  - Electrical

  These problems can be solved with existing computers
- Software enables
  - Communication
  - Control

  This is new, makes smart grid simulation into a super-computing problem, and will drive the architecture of next generation super-computers

Physics: mechanical and electrical

Generation



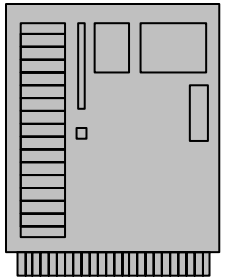
Transmission
& distribution

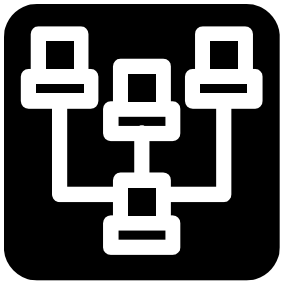
Load

- The physics of a power system <u>by itself</u> poses a peta-scale computing problem
- However, <u>by itself</u>, the solution of this problem is not particularly useful

Software: communication and control

Computerized, automatic control and human supervisory control





Digital communication networks

A smart electric grids requires **much greater** use of automatic, distributed controls enabled by modern communication networks

These controls rely fundamentally on software

Thus the Smart Grid is a Software Grid

And the Software Grid is a **software intensive system**

Software intensive systems: the role of simulation

- These systems can not be cost-effectively engineered without sophisticated simulators
  - Software in the loop simulation is the *only* cost-effective way to do development, testing, and training

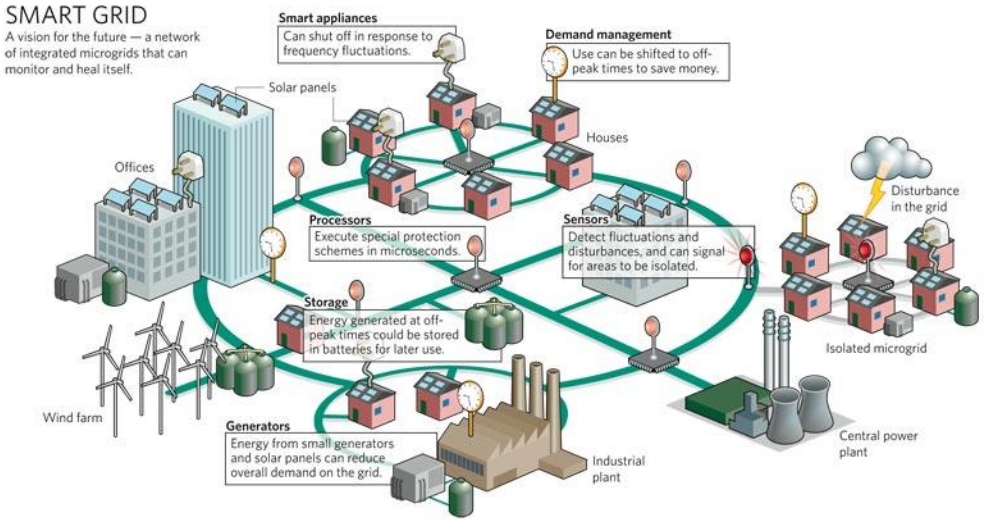
- In every industry, software intensive control has changed the focus of engineers from prototyping to simulation
  - Defense systems
  - Commercial aviation
  - Industrial automation
  - Digital communications

- The smart grid will force this change in the power industry

Iron birds, iron grids

- The “Iron bird”
  - Flight control software connected to a simulated airframe and proto-types of critical hardware
  - Giga-scale physics simulation
  - Software on hundreds of computers and their communication network

- The “Iron grid”
  - Operational and experimental software connected to a simulated power grid
  - Peta-scale physics simulation
  - Hundreds of thousands of computers and their communication networks



New computing challenge

- Need for super-computers for emulating computers: operational software executing on simulated hardware
  - Functional models of software
  - Instruction set emulation
  - Hardware virtualization
  - Models of communication channels, wired and wireless

- Integrate the simulated computers with the simulated physical machines that they control
  - Scalable algorithms for hybrid systems requires new research
  - Forces more refined sampling of physical dynamics

A sample of the coming challenge

- Consider ORNL's Jaguar
  - Approx. 200,000 Giga-Hz cores, approx. 1.75 peta-flops
- Assume x86 instruction set for all grid-wise computers
  - This is conservative, other instruction sets are common and more expensive to emulate
- Assume each on average uses a Giga-Hz processor
  - Some applications will need less, others more
  - Requires emulation of essential hardware
    - Sensors, actuators, etc
- A 100% efficient simulator for the Smart Grid's software will require half of ORNL's Jaguar
- The rest of Jaguar, and actually more, is needed for the peta-scale physics

Towards an “iron grid”

- Physics needs lots of floating point operations
  - Metric is floating point operations per second (FLOPS)
  - A peta-flop for the physics

- Software models, instruction set emulation, and hardware virtualization need lots of other types of operations
  - Metric is instructions per second (IPS)
  - Integer arithmetic
  - Stack management (push, pop)
  - Memory transfers
  - Bitwise operations
  - Everything except floating point operations
  - 10^9 MIPS = PIPS (peta-instructions per second)

- **Peta-flops physics + Peta-IPS emulation + Algorithms = Exa-scale computer !**

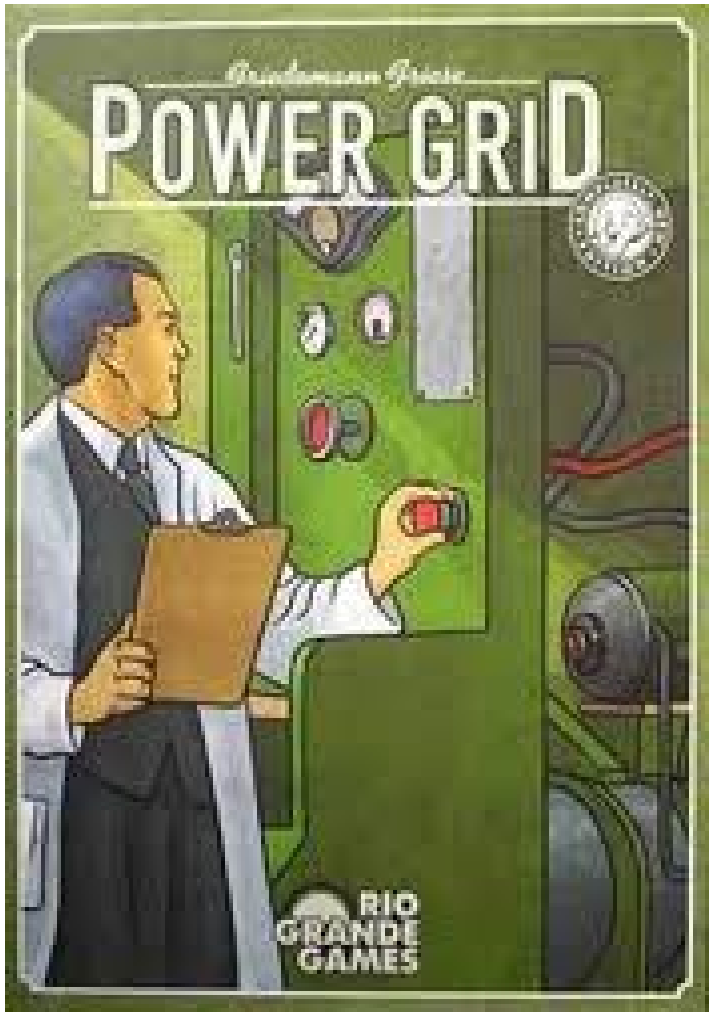
Given an “iron grid” today: immediate needs

- The computing power exists today to build an iron grid

- *<u>When it is built, it will be used to solve:</u>*
  - Practical diagnostic and prognostic applications based on PMU data
  - Dynamic stability problems anticipated with large amounts of wind and solar power

In 2 years: the power grid in a box

- Model calibration against sensor data is essential
  - Terabytes of data from Phasor Measurement Units, GridEye measurement devices, etc.
  - This data will be used to calibrate the “iron grid”
    - Infer line impedances, generator inertias, control system parameters, etc.
  - Model calibration is an optimization problem
- Industry wants this today but…
- This is an exa-scale computing challenge !



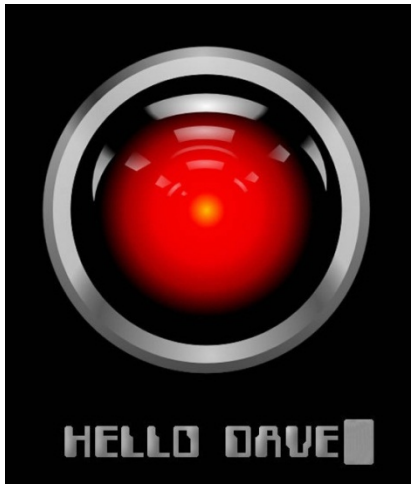
In 4 years: operator training for the "software grid"

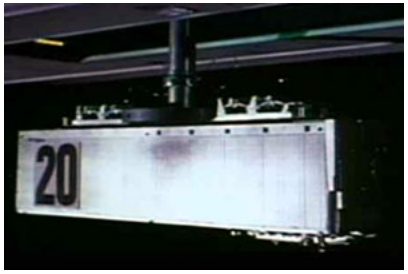
- Operator training
  - Operators interact with the "iron grid" in real time
  - Why advanced training?
    - 20% intermittent generation
    - Cyber-warfare
    - Distributed generation and energy storage
- The power industry wants this now, but…
- This is an exa-scale computing challenge !

"Train as you fight" for the smart grid is an exa-scale computing challenge

In 8 years: an automatic pilot for the smart grid

- The “iron grid” as an operational aide
- Exa-scale applications
  - On-line model calibration
  - Faster than real-time forecasting
  - Automatic course of action analysis
- Informing the operator’s actions minute to minute
- This is a zetta-scale computing challenge !





Conclusions

- The Smart Grid is a Software Grid
- Engineering the Software Grid requires a new kind of simulator and a new kind of computer
- The Software Grid will lead us to zetta-scale applications
  - Peta-scale for engineering
  - Exa-scale for training
  - Zetta-scale for control

Next generations supercomputers

- Super-computing for the Smart Grid is different
- Applications for the Smart Grid require a balance of FLOPS and IPS
- <u>This is a new and important direction in super-computing</u>

GridWise is a leading smart grid initiative

This is ***<u>IBM</u>*** Chairman Samuel J. Palmisano talking about how ***<u>IBM</u>*** is going to help build a smart grid.

Start today to meet tomorrow's smart grid's needs