The Impact of ORNL's HPC Power Load Swings on the TVA Infrastructure

20 Years of Excellence in Computational Science

OLCF

Oak Ridge Leadership Computing Facility

1992–2012

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U.S. DEPARTMENT OF ENERGY | Office of Science

Oak Ridge National Laboratory
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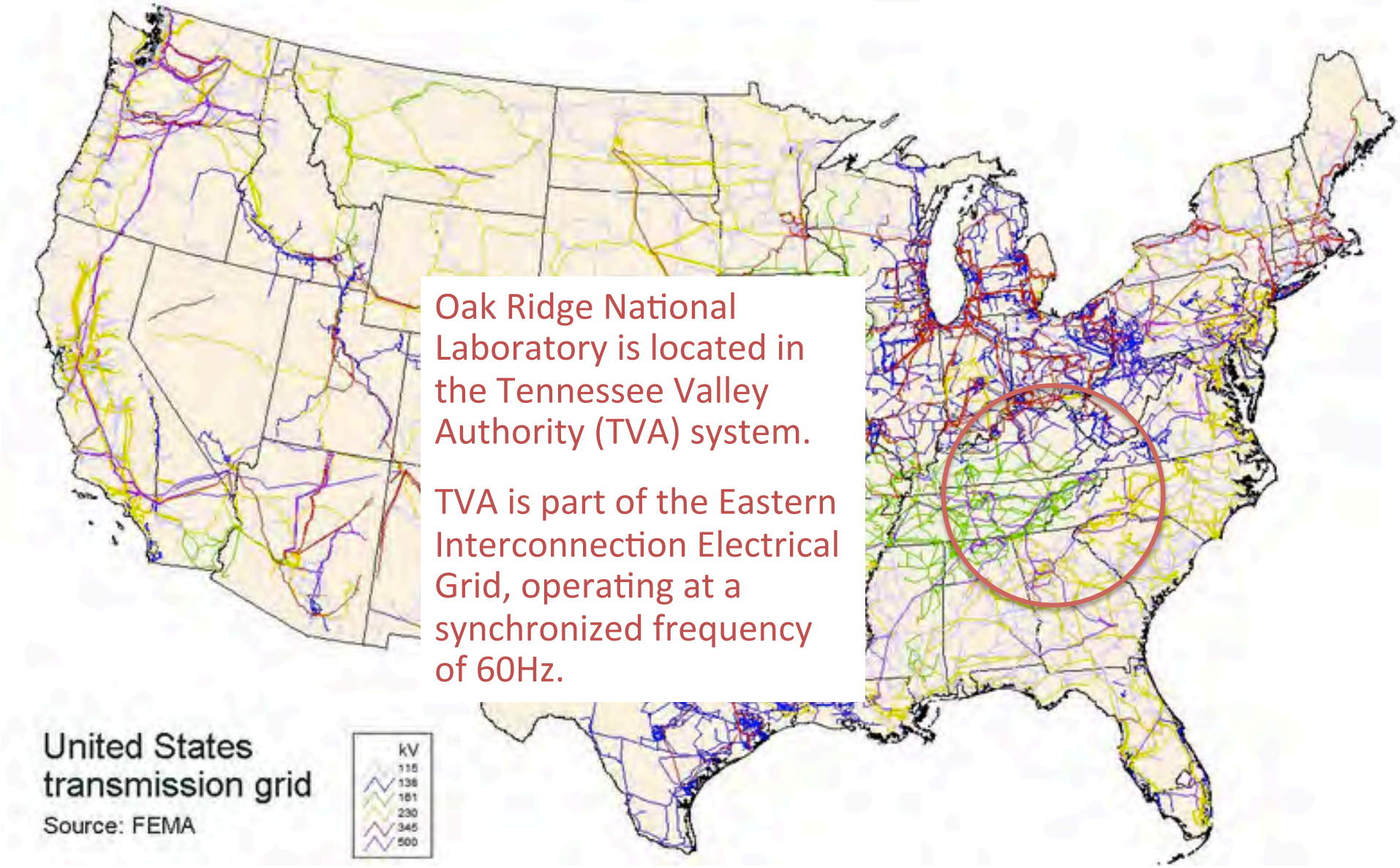
United States High Voltage Transmission Grid

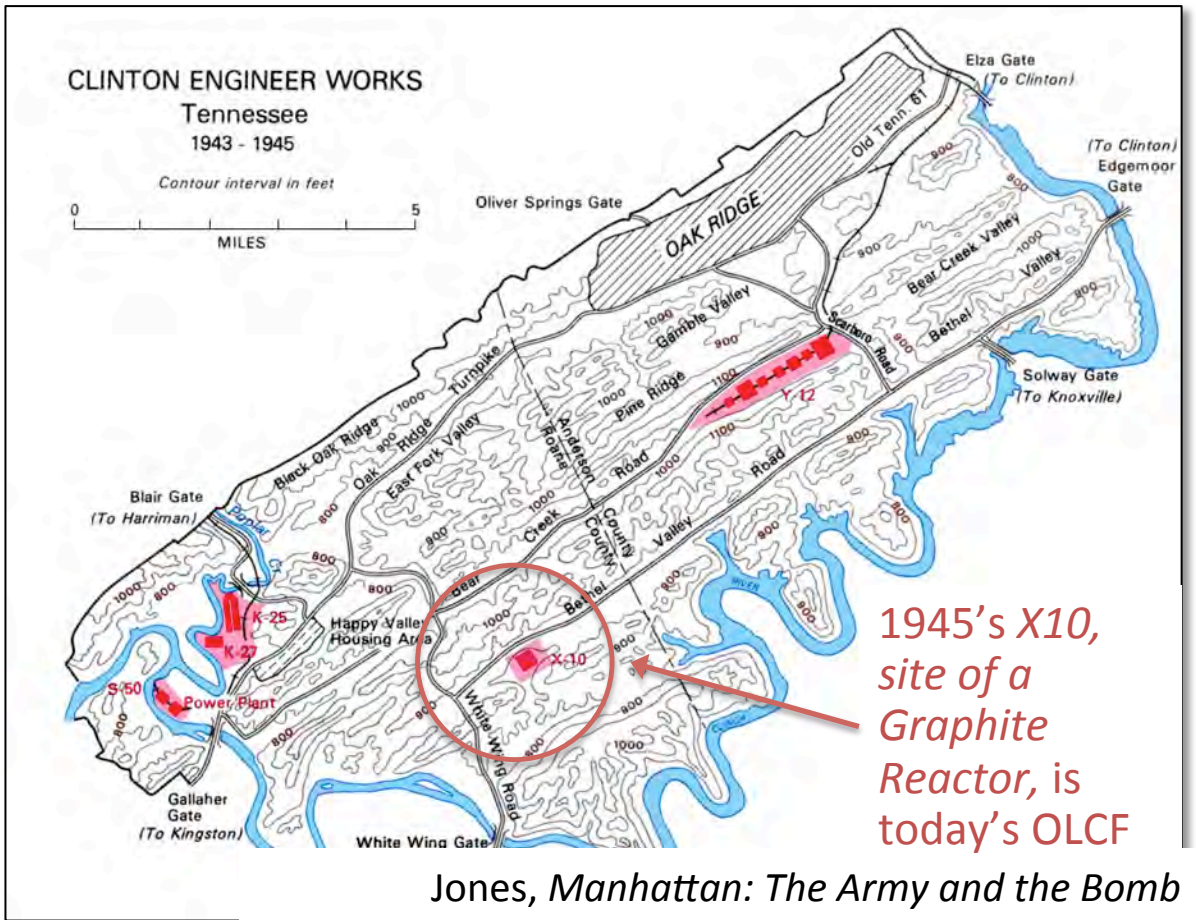


Oak Ridge National Laboratory is located in the Tennessee Valley Authority (TVA) system.

TVA is part of the Eastern Interconnection Electrical Grid, operating at a synchronized frequency of 60Hz.

Legacy of the TVA Infrastructure at ORNL - The Clinton Engineer Works (CEW)

- In the 1940's, in support of the Manhattan Project, TVA built out significant electrical distribution infrastructure in to the East TN area, tying their system in to the Clinton Engineer Works.
- TVA's electrical power grid for the CEW included large (161kV) transmission lines from multiple sources.
- CEW demand in 1945 was *0.9% of the entire national energy demand*.
- *What is the current demand relationship between ORNL and TVA?*

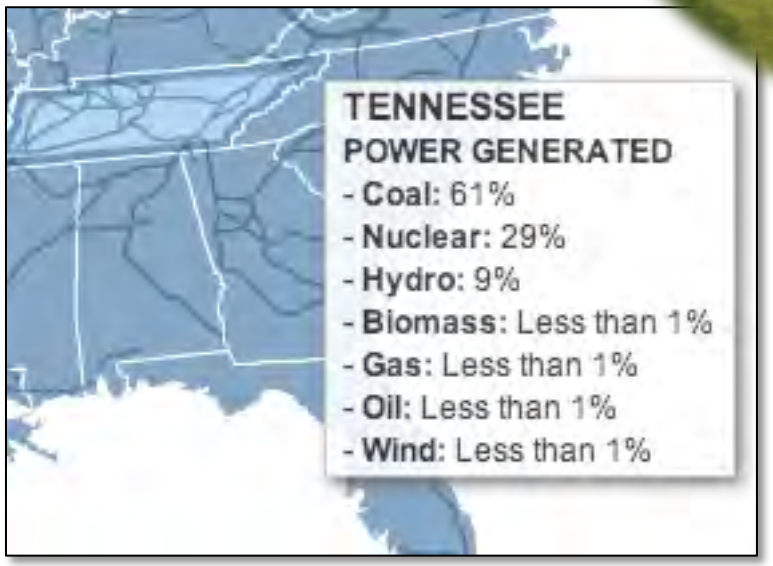


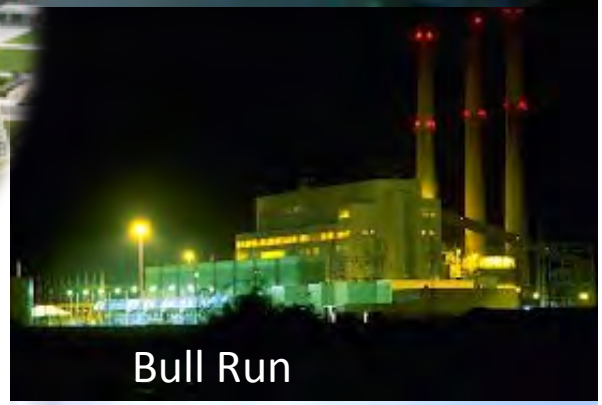
1945's *X10, site of a Graphite Reactor,* is today's OLCF

Jones, *Manhattan: The Army and the Bomb*

TVA and the Interconnection to Oak Ridge National Laboratory

Separate 161kV transmission lines from three diverse routes provide reliable power to the ORNL facilities





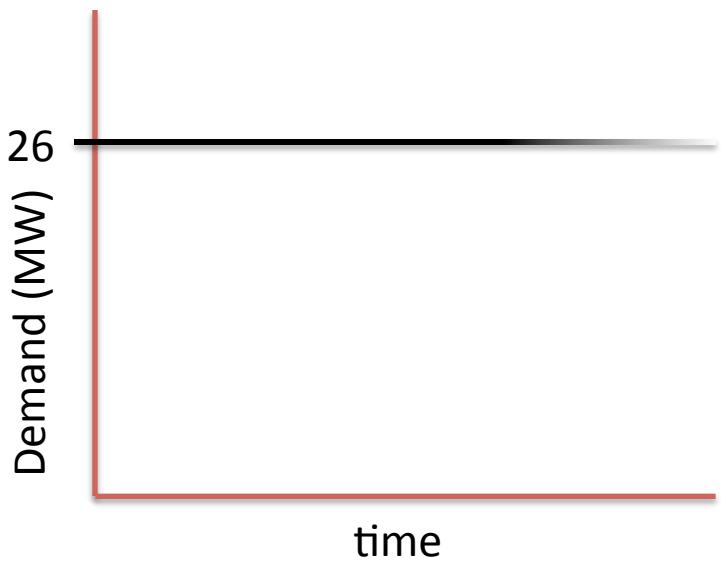
Diversity of power sources provides:

- Higher reliability
- Financial mechanisms for consistently delivering low-cost power (5-6 cents/kW-h)

Disparity of the Grid Models and Demand Reality

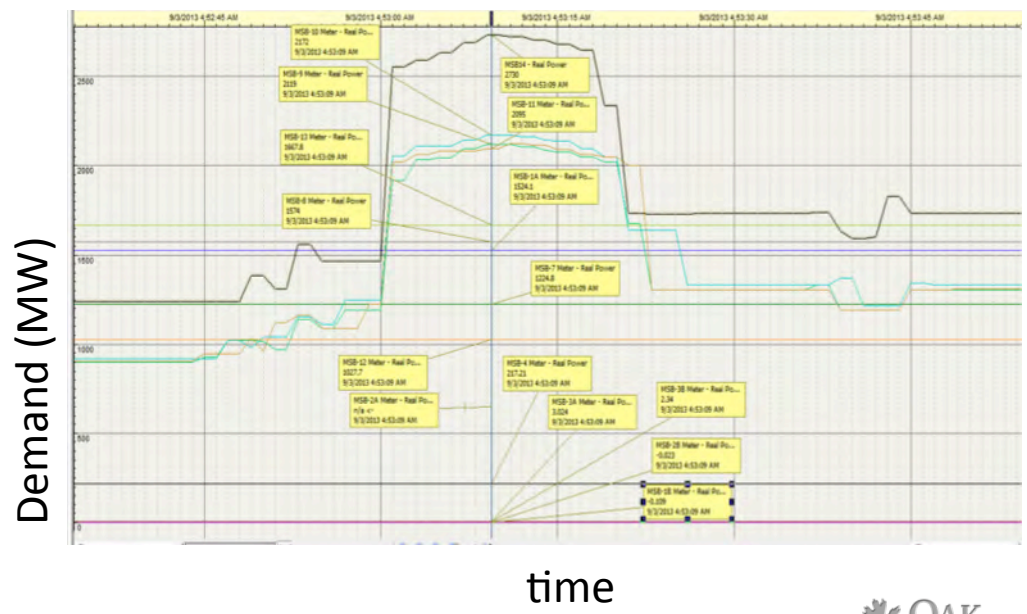
How TVA Models ORNL (circa 2008)

- 26MW Steady State Load
  - No variation in demand due to time of day, time of year, surge demands, instruments, project timelines…



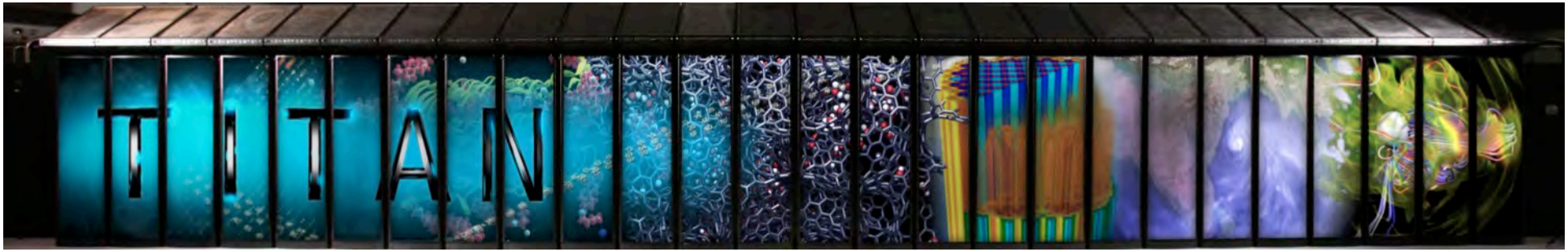
Demand Reality

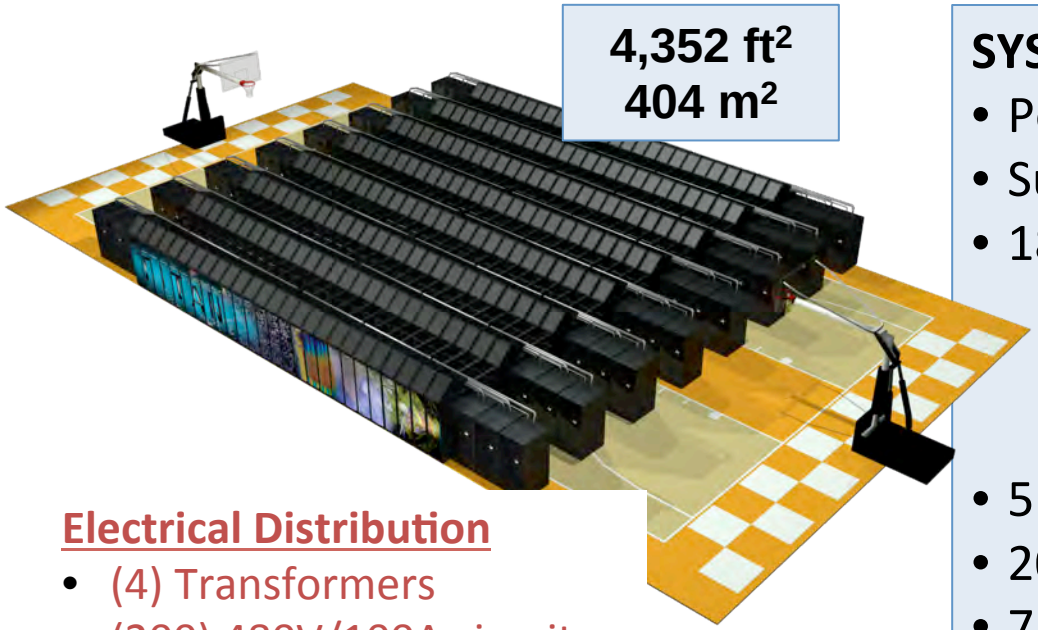
- Actual conditions vary
  - Heating and cooling demand
  - Instrument (SNS et al) demand
  - HPC system demand at instantaneous, intermediate, and long-term scales.



ORNL's Cray XK7 Titan

- A Hybrid System with 1:1 AMD Opteron CPU and NVIDIA Kepler GPU





4,352 ft²
404 m²

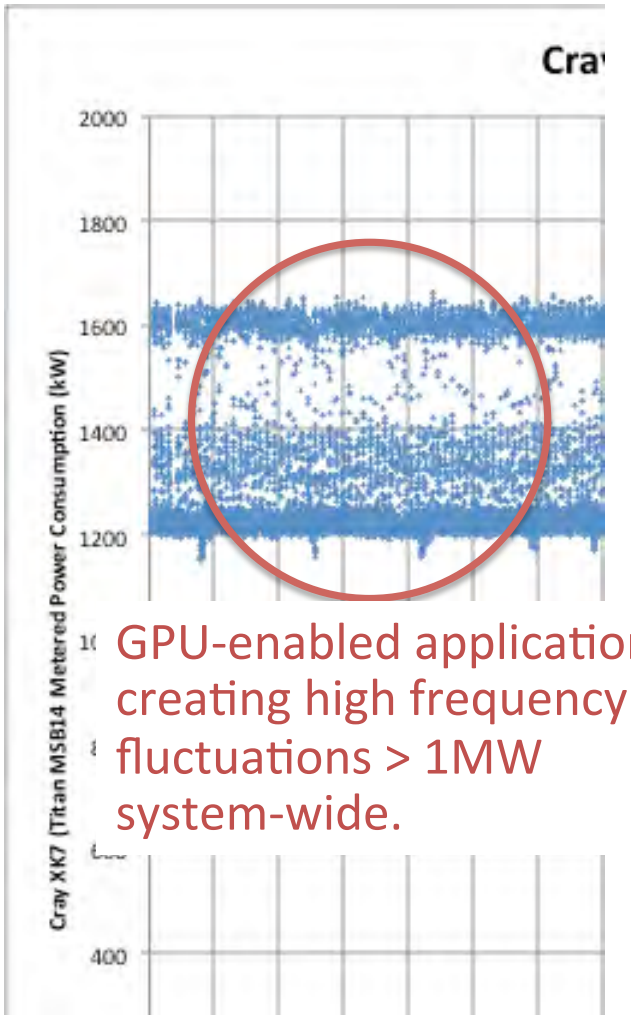
Electrical Distribution

- (4) Transformers
- (200) 480V/100A circuits
- (48) 480V/20A circuits

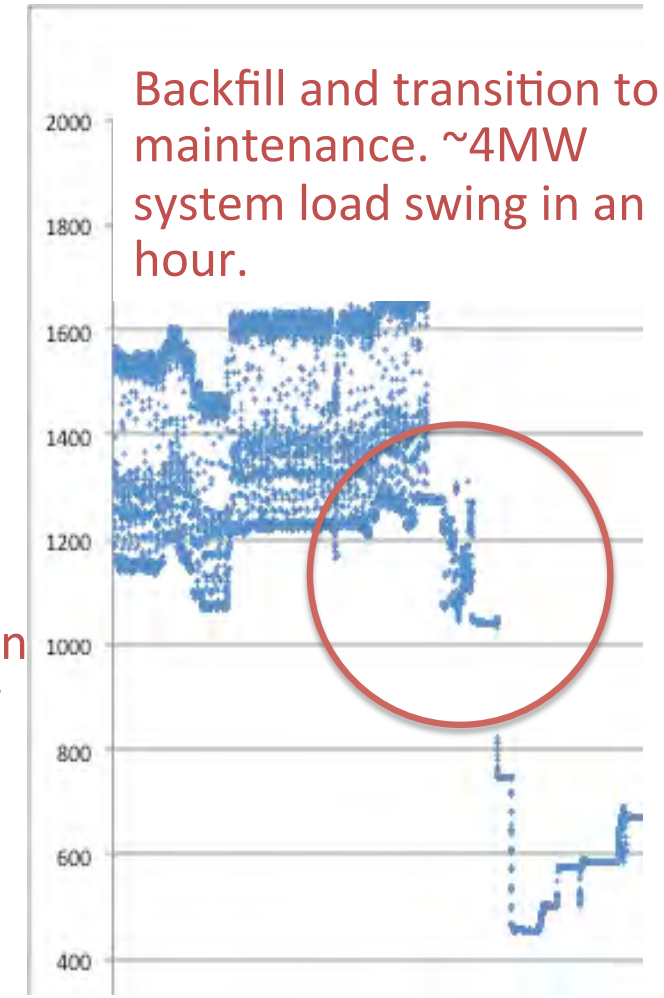
SYSTEM SPECIFICATIONS:

- Peak performance of 27 PF
- Sustained performance of 17.59 PF
- 18,688 Compute Nodes each with:
  - 16-Core AMD Opteron CPU
  - NVIDIA Tesla "K20x" GPU
  - 32 + 6 GB memory
- 512 Service and I/O nodes
- 200 Cabinets
- 710 TB total system memory
- Cray Gemini 3D Torus Interconnect
- 8.9 MW peak energy measurement

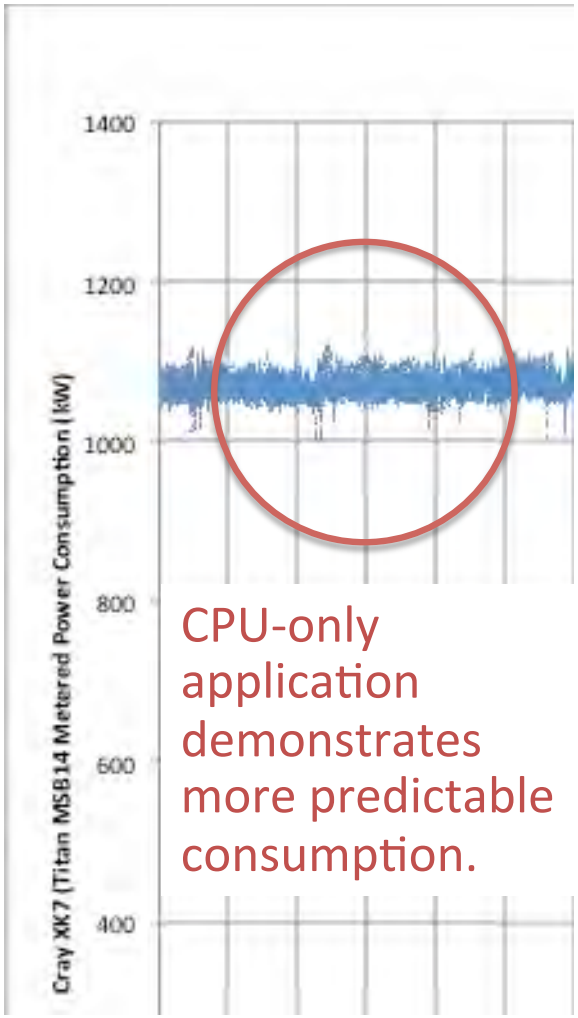
A Day in the Life of a Cray XK7 Titan Transformer



GPU-enabled application creating high frequency fluctuations > 1MW system-wide.



Backfill and transition to maintenance. ~4MW system load swing in an hour.



CPU-only application demonstrates more predictable consumption.

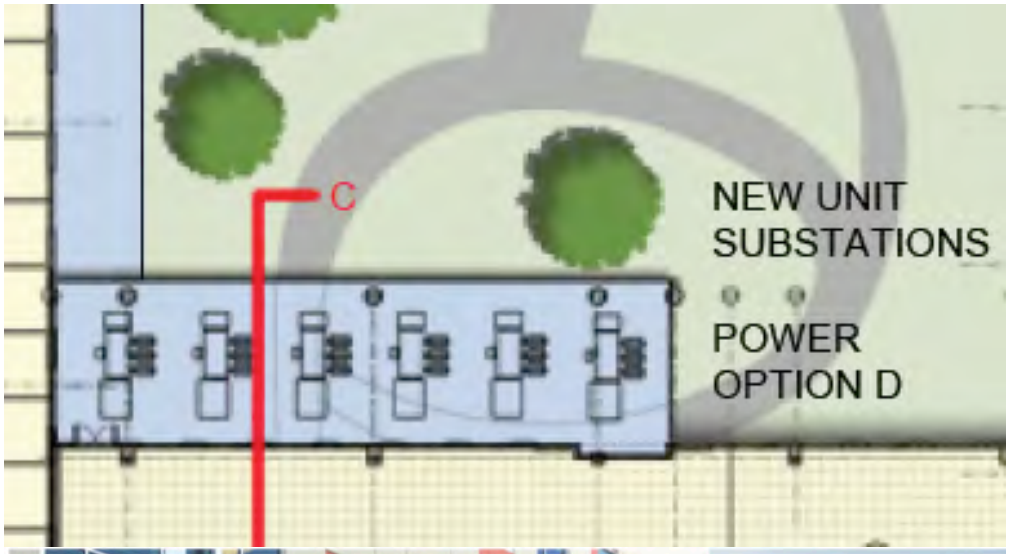
The Cray XK7 demonstrates significant variation in the demand characteristics. What is peak? (9MW inst.) What is typical? *Depends*… What is mean? (5.9MW inst.)

Demand Swings Due to HPC or Instrument Requirements
- Protection of the Utility Provider's Transmission Lines

- ORNL can (and does) currently generate fast load swings of ± 4 or 5 MW across short periods of time (measured in cycles).
  - HPC Systems, including Titan, Kraken, and Gaea
- Larger movement of ± 10-12 MW for other planned activities.
- Large science instruments at ORNL can also contribute to the demand swings
  - A single beam line at the Spallation Neutron Source (SNS) can introduce demand loads of 1.4MW

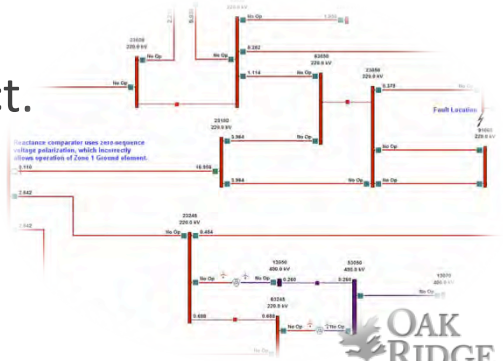
Future HPC Systems Will Exacerbate Demand Swings - Scheduled Electrical Infrastructure Improvements

- *CORAL Project Mission Need: 20MW of Power for a new 100-200PF Technical Load*
  - Solution Space Outside the Data Center:
    - Diverse routes and substations for high- and medium- voltage distribution systems
    - 13.8kVAC medium voltage delivery to CSBx (Facility/System demarc)
    - Build Out Schedule in 2014-2016, integrated with Mechanical Improvements
  - Solution Space Inside the Data Center
    - 600VAC or 480VAC distribution
- *Impact: 12-16MW Load Swings (both fast and slow transitions)*



Why Do We Care?

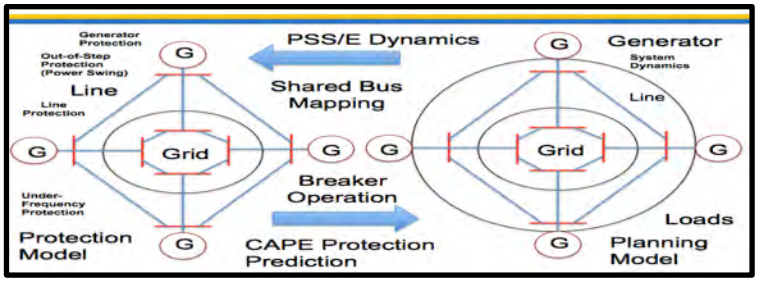
- The installation of an additional 20MW of power will increase *total* technical load capability to more than 40MW at OLCF HPC Facility.
  - Large systems can introduce large demand swings.
- What is the impact to the electrical distribution infrastructure that serves us? Do we introduce production risk to the delivery of stable/reliable power?
- ORNL is addressing this issue through the development of a high resolution dynamic model that:
  - combines the TVA power system and generation fleet dynamics and associated protection schemes with
  - a high resolution detailed ORNL power system dynamic load model with associated protection schemes
  - Provides a highly flexible tool for assessing system impact.

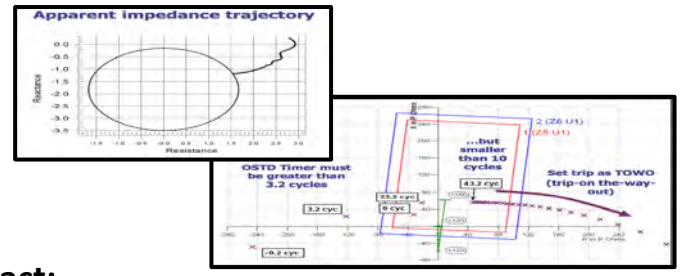


Dynamic Protection-Planning Simulation

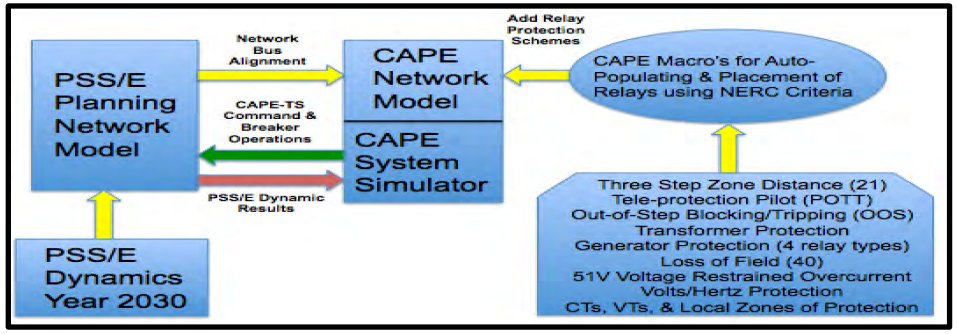
Travis Smith*, Ashok Gopalakrishnan**, Russell Patterson***, Daryl Coleman**, Paul McGuire**, Meyer Kao***
*ORNL, ** Electrocon International Inc., ***Patterson Power Engineers, LLC

Objective: Consolidated planning dynamics and system protection simulation model for assessing future high penetration of renewable generation and impact on protective relaying schemes during power system disturbances.





- Assess the impact of high penetration of renewable generation on grid stability during system disturbances.
- Evaluate impact of protective relaying schemes on grid stability during fault conditions or other system disturbances.
- Assess effectiveness of protection algorithms i.e. out-of-step blocking / tripping in maintaining stability of the network.
- Evaluate wide-area protection schemes, remedial action schemes, etc.

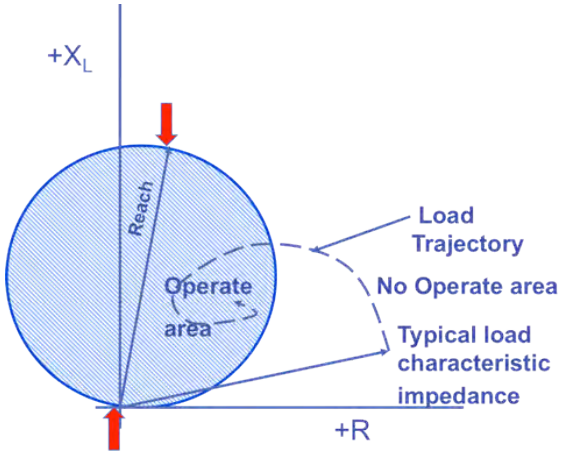


Impact:

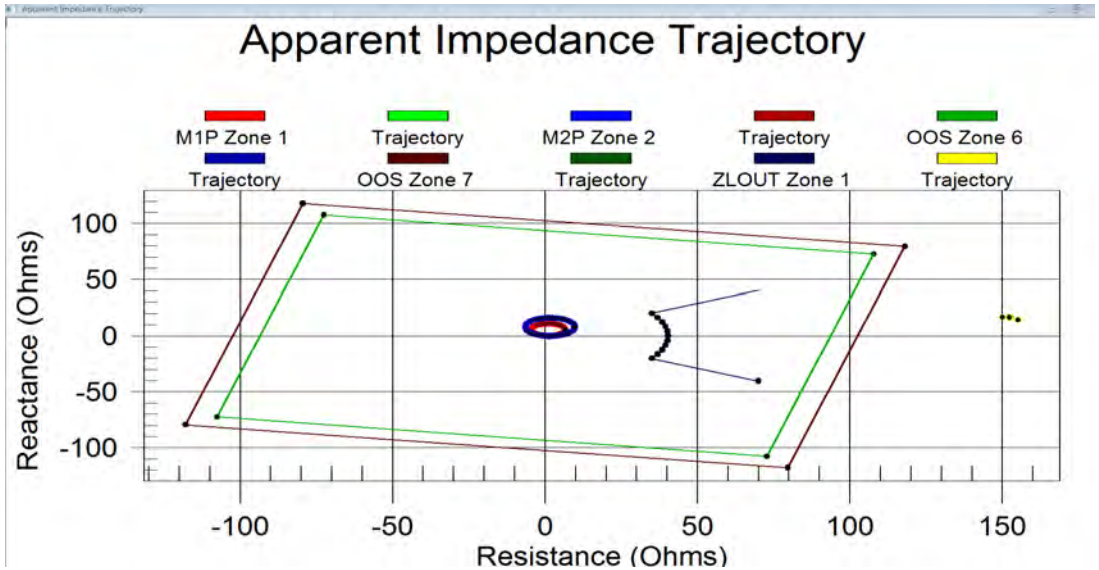
- Uncover threats to network stability caused or amplified by protection system in future power systems with renewable generation technologies.
- Suggest protection changes/settings
- Assure adequacy of protection for credible contingencies and planned outages.
- Research, development, and simulation of future special protection schemes.

Measuring the Impact to TVA Using ORNL's Dynamic Model

Using ORNL's model, introduce disturbances, and evaluate the impact to the Branch Power Flows and the Apparent Impedance sensed by protective out of step relays in the TVA system.



- Case 1: 1.5MW disturbances (typical and existing)
- Case 2: 20-30MW disturbances (extreme and future)



Preliminary Model Results

- Current ORNL MV system model used; TVA HV system model contained basic elements needed for preliminary check.
- Worst case: 30 MW Load at ORNL cycled every 3/4 of cycle for 5 seconds
  - Out of step relay operation within a 30 cycle window:
    - If any out-of-step event is seen by the relay it will start a timer. If the event continues and is seen again within the 30 cycle timer window the line will trip due to load swings and/or other additional contingencies which created the instability .
  - Model was run with .99 pf and approximately .71 pf
- Results indicated that these load and pf swings *would not* impact out of step relay
  - Voltage drop at ORNL HPC system was high for .71 pf as would be expected
- Future collaboration with TVA to update their model
- Based on this preliminary analysis, the HV transmission system in the ORNL area is very stiff and can accommodate fast load switches as might be produced by HPC
- Other areas of the country where HV generation and transmission systems aren't as stiff should perform a similar analysis to verify that HPC loads will not have detrimental effect on the utilities' system.

Questions ?

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