# The Power Grid & HPC Integration

Michael K Patterson, Intel
Josip Loncaric, LANL

8th Annual EE HPC WG Workshop, SC17 Denver, Colorado
https://eehpcwg.llnl.gov/pages/conf_sc17a.htm

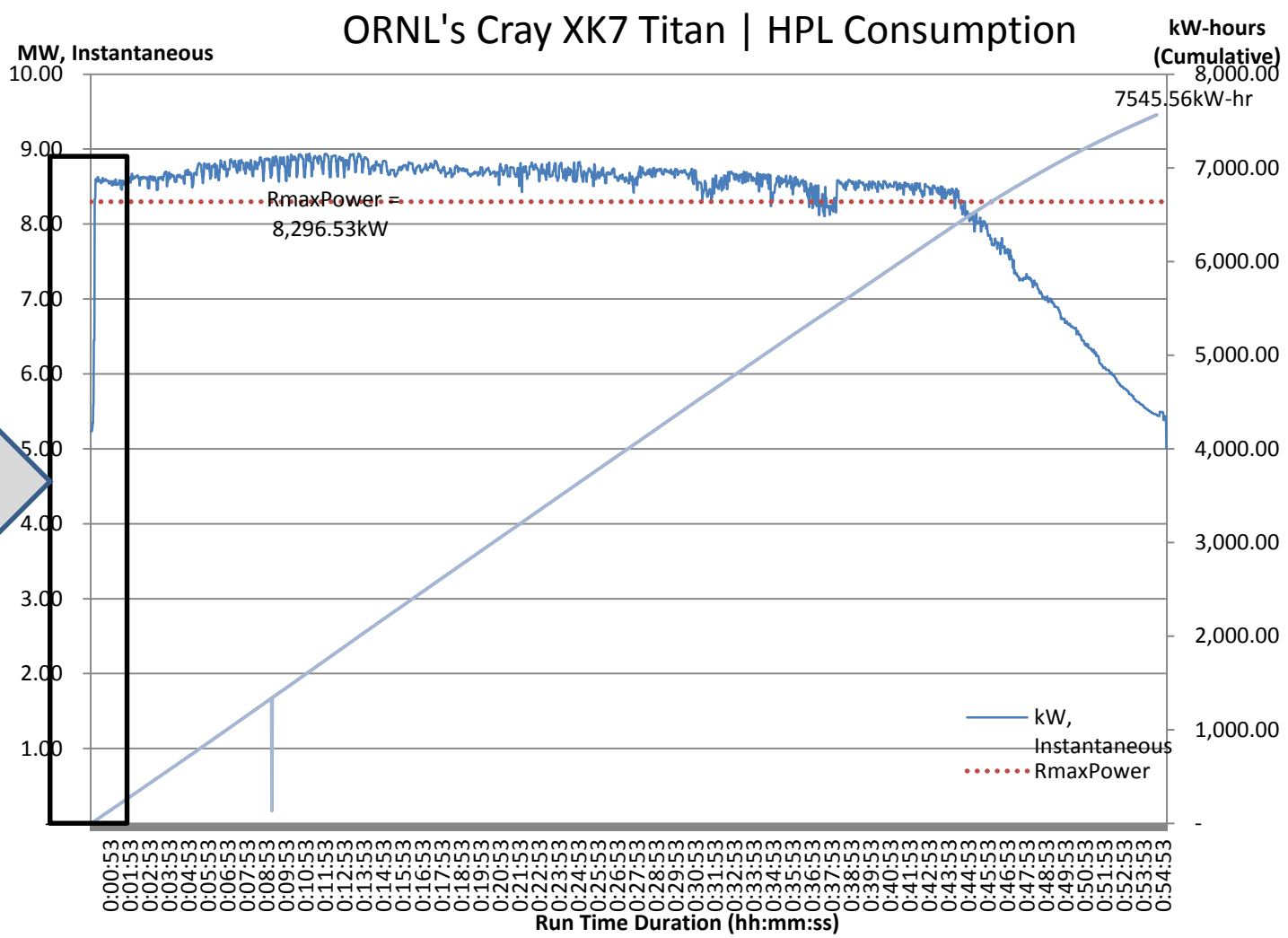
# Session Agenda (Sunday, 13:30-15:00)

- Site Updates (30 minutes, 6 minutes each)
  - ORNL – Jim Rogers
  - NREL – Steve Hammond
  - LLNL – Anna Maria Bailey
  - LRZ – Torsten Wilde
  - LANL – Grant Stewart
- Main Speaker – Ben Kroposki, NREL (40 minutes)
  - *What you need to know about the power grid before adding a 10 MW step-function load generator* (my title, Ben to change to suit, but my goal is to educate the users on the grid, some combination of: how it works, how it deals (technically and financially) with bumps in demand, how coal, hydro, nuclear, wind, solar, gas all play together, how we can mess it up, what to watch for in operations and planning, grid time scales (how does the grid flex? How fast can peaking come on line), do 1 MW steps matter, do 10 MW steps matter, do 50 MW steps matter?, etc…)
- Panel – Q/A (20 minutes)
  - Ben and our 5 site reps
  - Mike & Josip as moderators

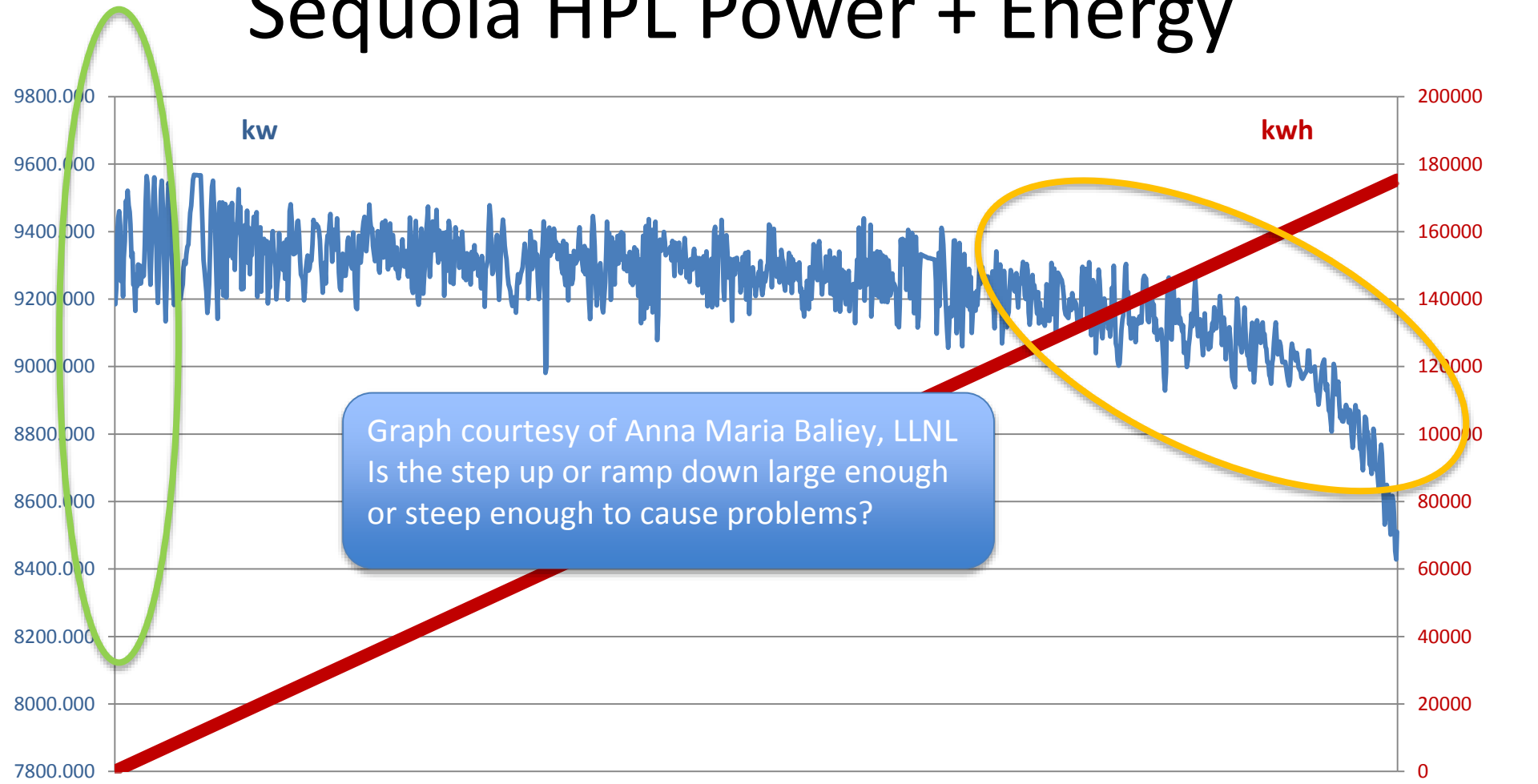
Thanks to Jim Rogers and ORNL for this chart

Ramp = $\Delta P/\Delta t$

How steep a ramp $\Delta P/\Delta t$ is too steep, how big a step $\Delta P$ is too big?



# Sequoia HPL Power + Energy



# Oak Ridge National Lab

## SITE UPDATE

# Preparing for Future HPC and Lab-Wide Electrical Distribution Requirements

**Jim Rogers**

**Director, Computing and Facilities**
**National Center for Computational Sciences**
**Oak Ridge National Laboratory**

# Dr. Patterson's Instructions

- Who at your site owns the relationship with the utility?
- How often do you talk to the utility? (Annually, monthly, daily?) What do you regularly communicate?
- Do you communicate planned "events"? (Linpack etc, maintenance, start-ups, back-up generator operations)
- Is communications a two-way street? What do they call you about?
- What rate do you pay? How is it structured? (use+peak?) What time is your "peak" charge over? Week, month, qrtr? Time of day pricing? Seasonal pricing?
- Any incentives for renewables? Or on-site generation?
- Do you risk penalties? How are they put into play
- Has their been any talk of "demand response" with the Utility?
- What is your site power use/range? Your data center power use/range?
- What is your utility planning horizon? 1 yr, 5 yr, 10 yr? (are you talking to them about future demand at these different time scales?)
- Have you ever "bumped" the power grid with unexpected consequences?
- Do you have multiple feeds to your site? What level of redundancy or flexibility does this provide?

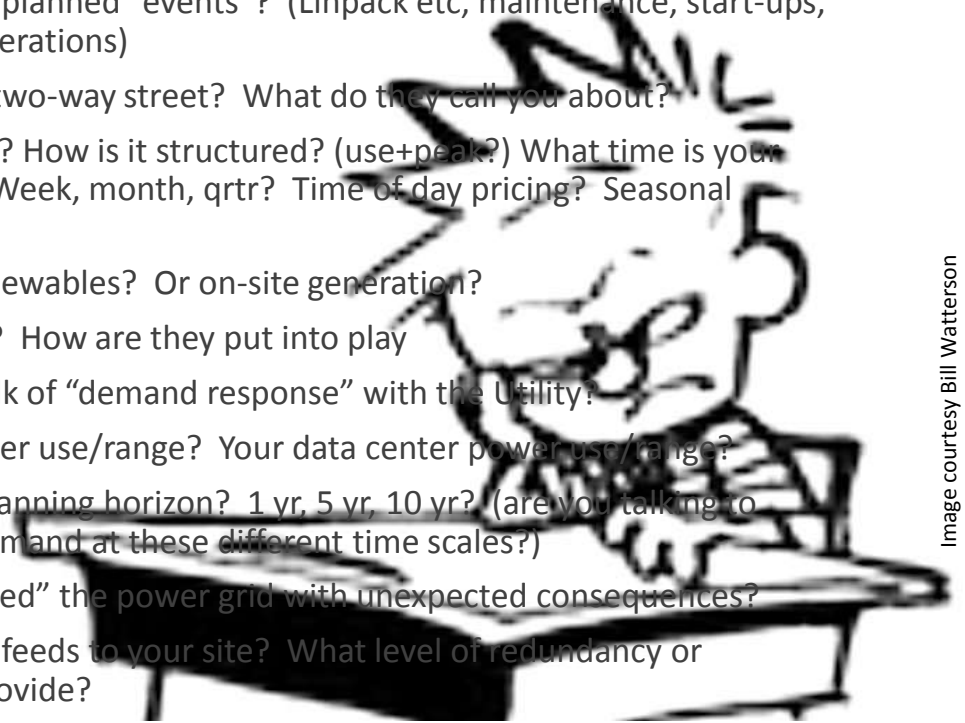
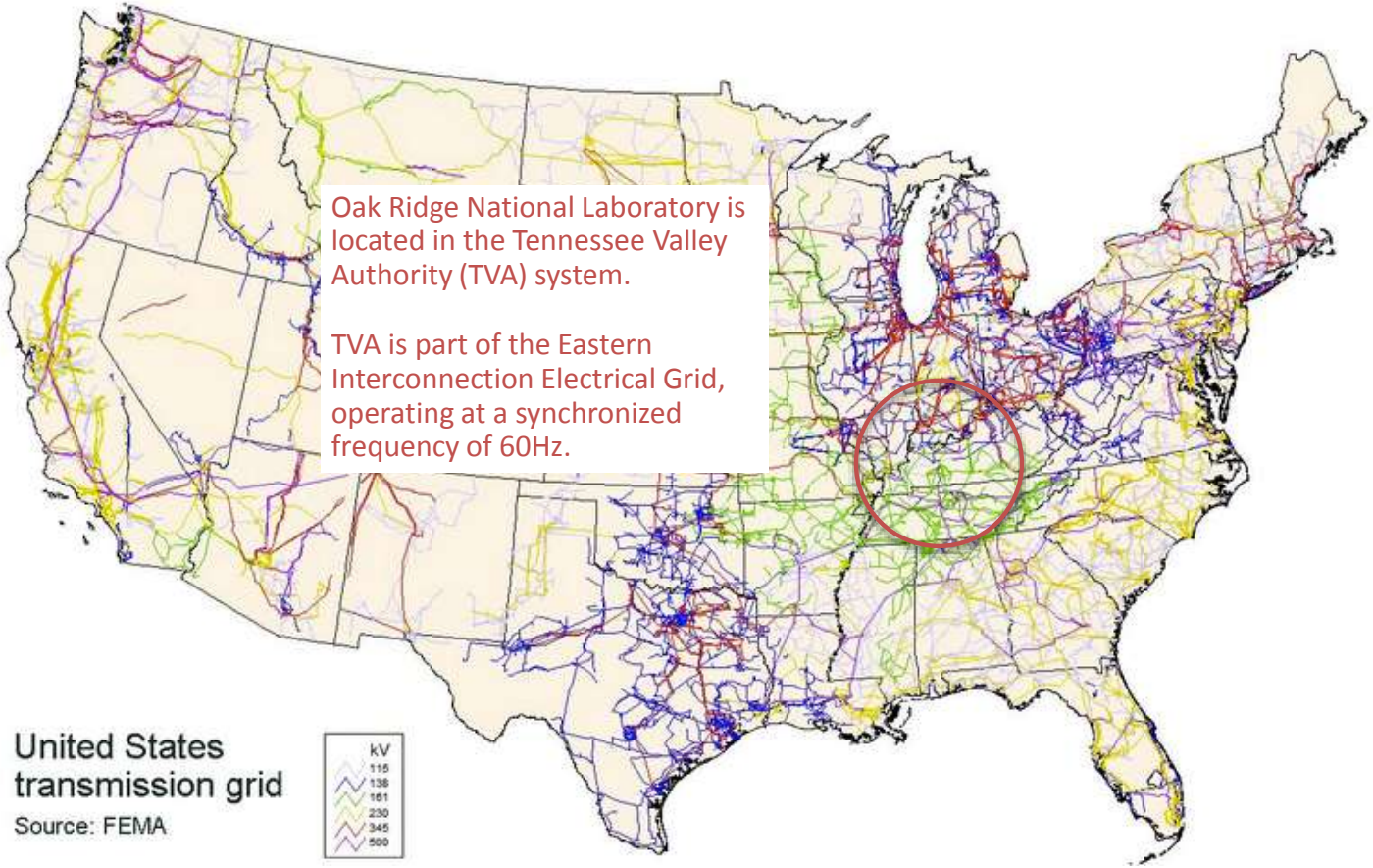


Image courtesy Bill Watterson

# United States High Voltage Transmission Grid

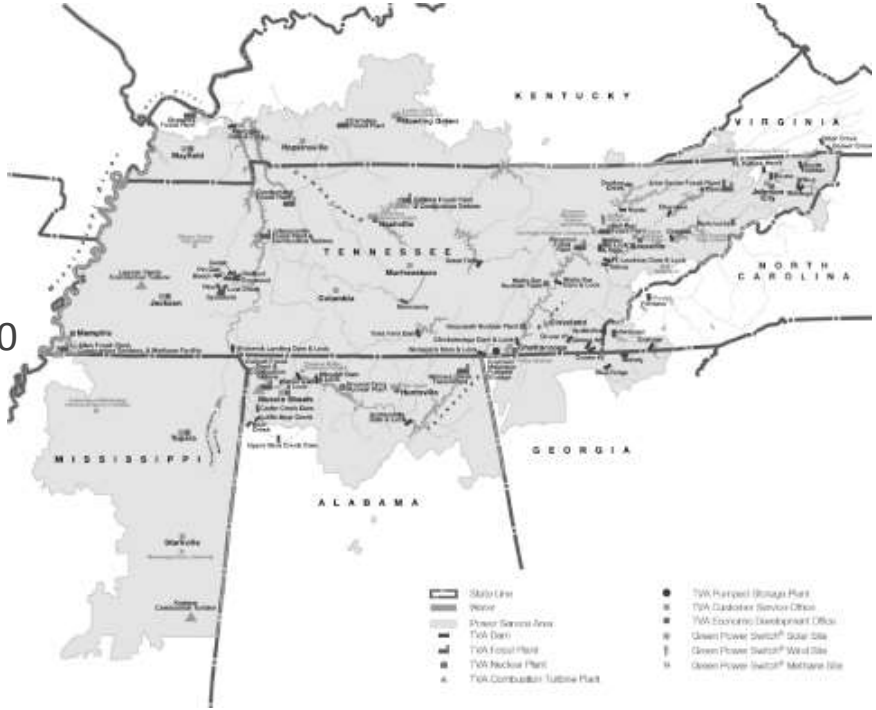



Oak Ridge National Laboratory is located in the Tennessee Valley Authority (TVA) system.

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

# TVA Transmission System

- Scope: 154 local power providers, serving 9 million people in the Tennessee Valley across 80,000 square miles in seven states.
- 69 Interconnections with 12 neighboring electrical systems
- 99.999% reliability since 2000
- 2,500 circuit miles of 500-kilovolt transmission lines
- 11,500 circuit miles of 161kv transmission lines
- 2,200 circuit miles of other transmission lines



# TVA Production Assets

8 fossil plants *(41 active units)*

3 nuclear plants *(7 units)*

29 hydro plants *(109 units)*

1 pumped storage hydroelectric plant *(4 units)*

9 natural gas combustion-turbine plants *(87 units)*

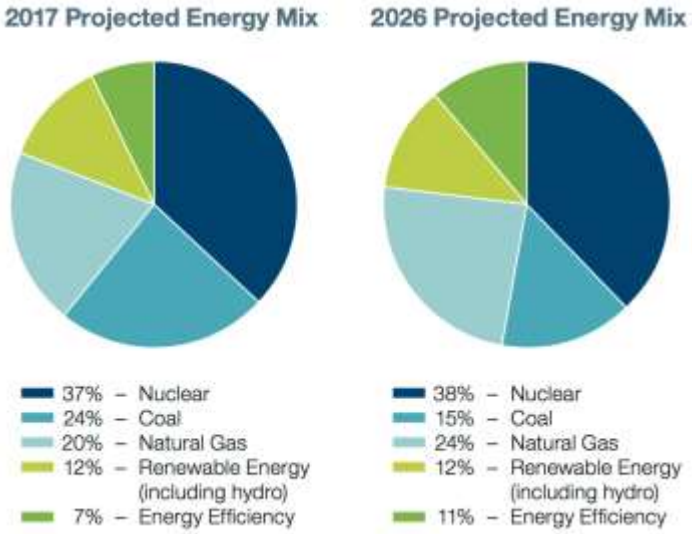
7 natural gas combined-cycle plants *(11 units)*

1 diesel-generator site *(5 units)*

15 solar energy sites

1 wind-energy site

# TVA Energy Portfolio



# TVA Local Assets – Total Net Summer Capacity

- Norris Dam - 127 MW
- Cherokee Dam - 141.6 MW
- Douglas Dam - 177.9 MW
- Melton Hill – 79.2 MW
- Fort Loudon – 168.2 MW
- Watts Bar - 193.9 MW

- Bull Run- 870 MW
- Kingston – 1398 MW

- Watts Bar Unit 1 – 1123 MW
- **Watts Bar Unit 2 – 1123 MW**

*A view inside Watts Bar Unit 2's reactor vessel, which is in its first scheduled refueling outage. The outage was planned as part of normal operations and integration into the generation fleet. TVA will replace 72 of the 193 fuel assemblies with new fuel for the next 18-month cycle.*



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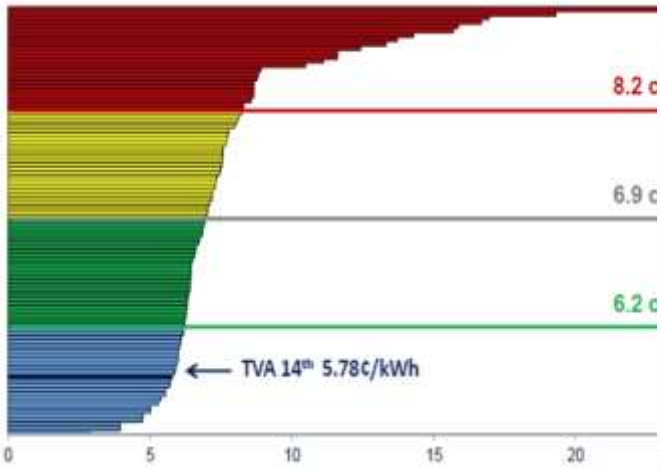
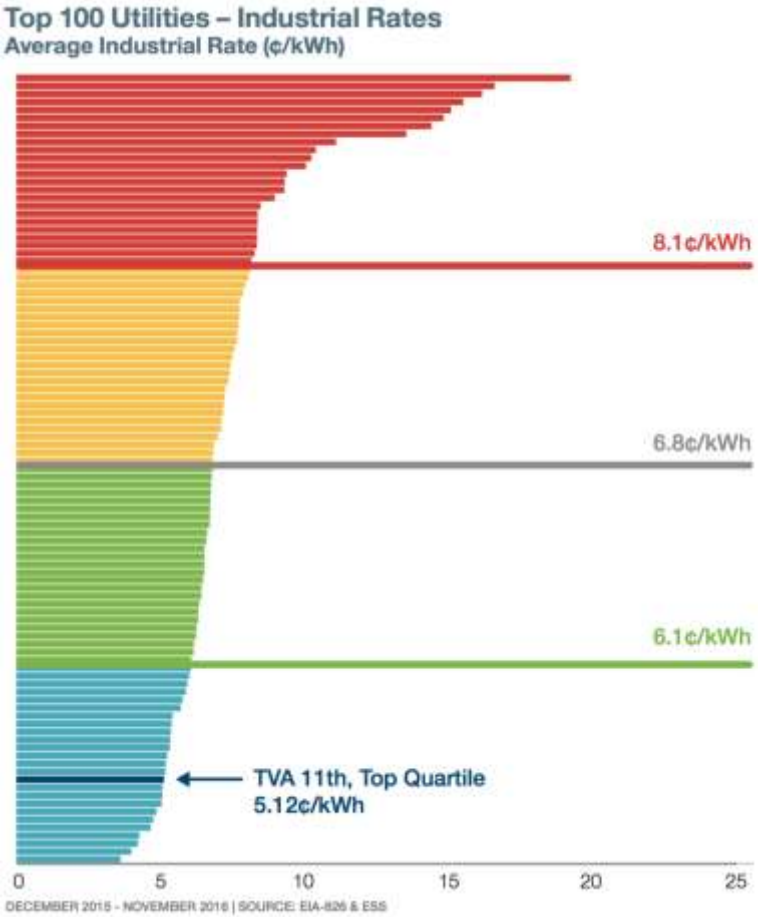
# Industrial Energy Rates

**CY2014**

12-month average industrial rates of top 100 U.S. utilities




**CY2016**



# Last Mile: TVA and the Interconnection to ORNL

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

Oak Ridge Reservation distributes power at 13.8kV from 7 large (70MW) sources

Diversity of power sources provides:

- Higher reliability
- Financial mechanisms for consistently delivering low-cost power

# Disparity of the Grid Models and Demand Reality

- How TVA Models ORNL (circa 2008) (no change in 2017)

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

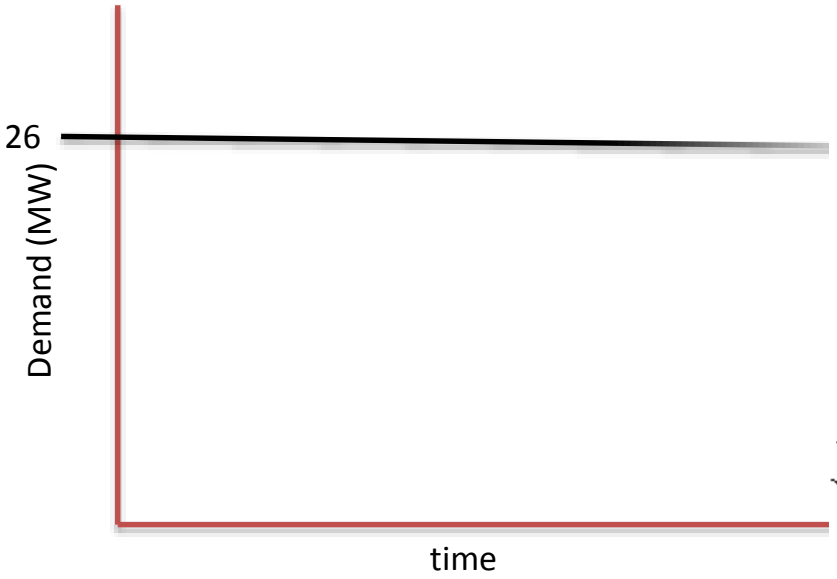
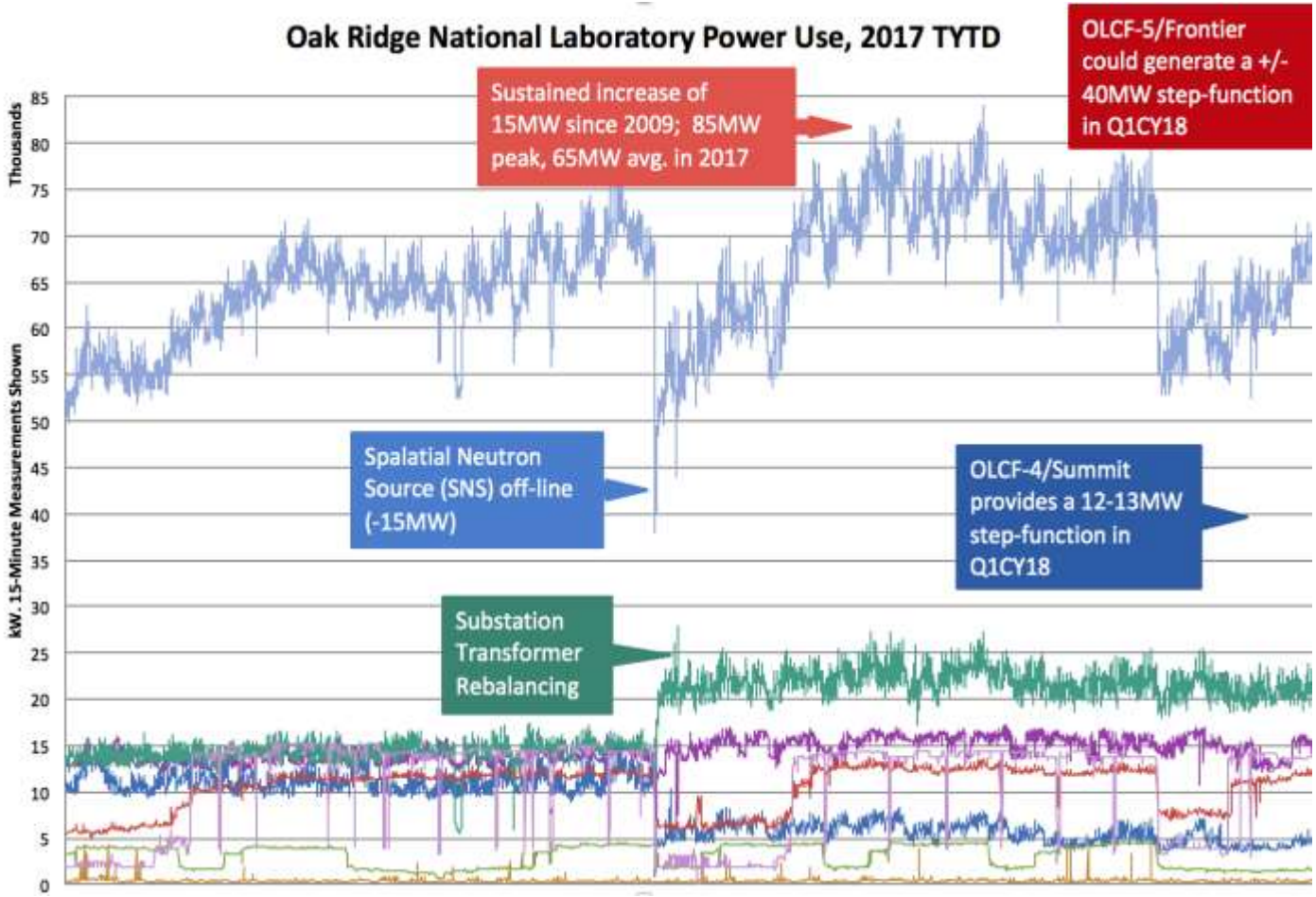


Image courtesy Bill Watterson





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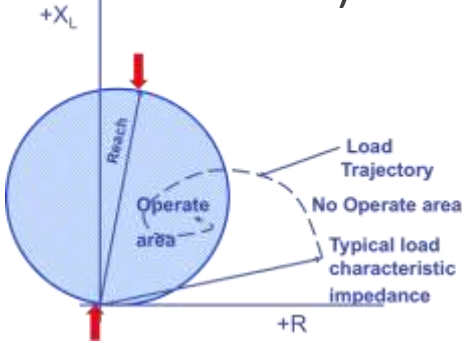
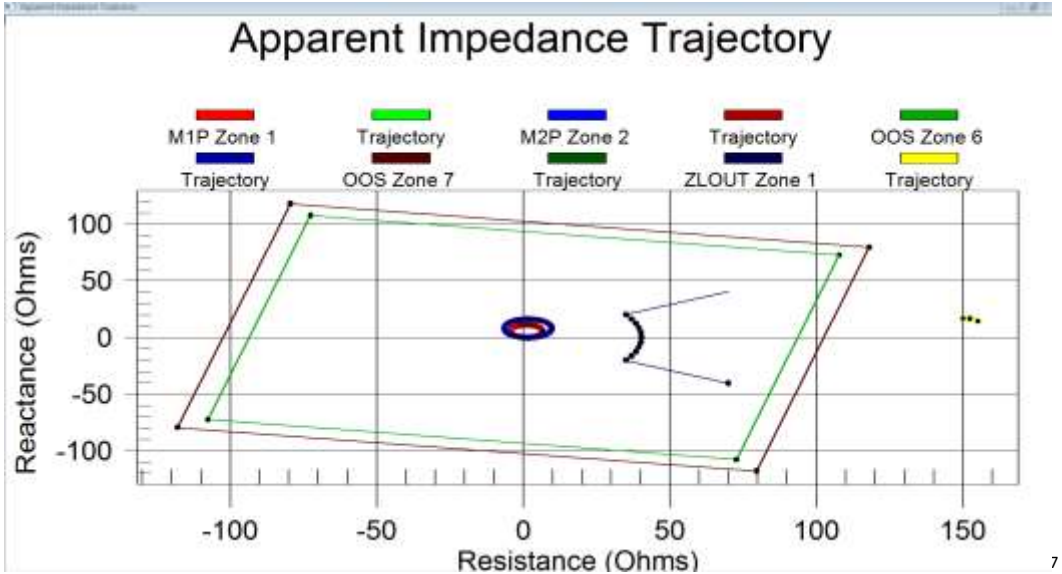
# Measuring the Impact to TVA Using ORNL's Dynamic Protection-Planning Simulation Model (Travis Smith et al)

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.



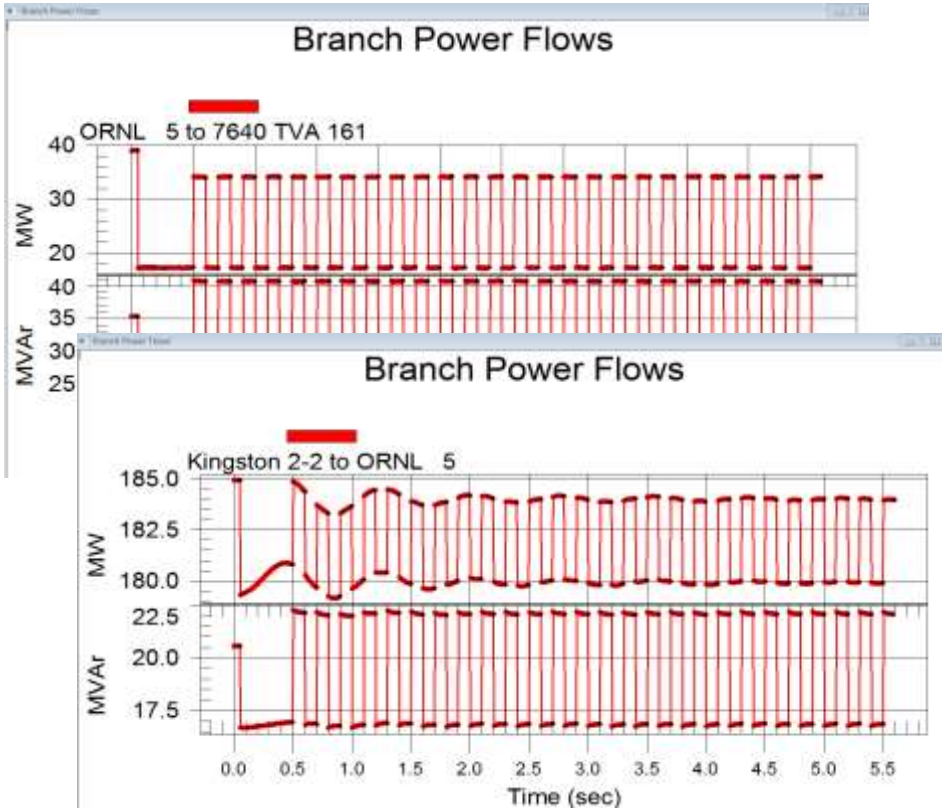

20-30MW disturbances (extreme and future)



# Impact on TVA: Modeling 100ms/30MW demand fluctuation at ORNL HPC Facility

Introduce a (future/large) 30 MW demand fluctuation on an HPC resource (look downstream at the ORNL Main Bus Power Flow) …

Examine the impact on a specific 161kV TVA transmission line…





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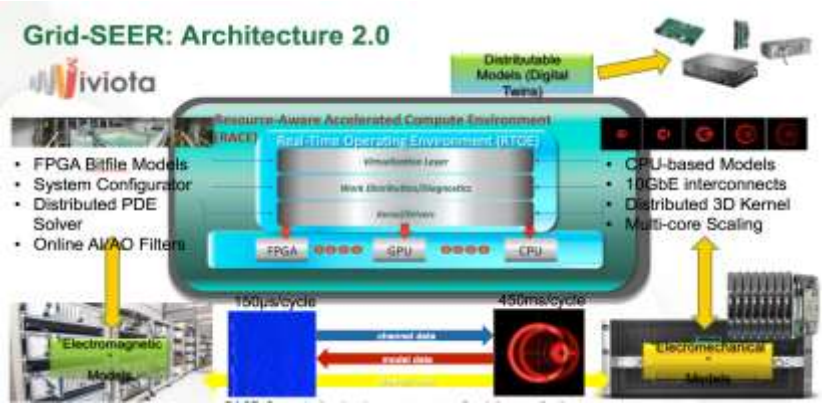
# Next Steps – PMUs for Accurate Data Collection

- ORNL is installing high fidelity three-phase time synchronized phasor measurement units on each of Summit's 480Vac MSB HPC loads.
- ORNL has plans to install these phasor measurement units on existing and future Medium Voltage 13kV HPC feeders both at substation and the load. Additionally ORNL will install these measurement units on HV 161kV lines.

  - These measurement units provide high fidelity voltage and current measurements to the ORNL HCE project for applying advanced grid modeling techniques
  - The grid model will allow validation and improvement of the power supply models
  - Advanced models combined with measurements enhance power supply planning efforts and improve reliability for fault location, isolation, and restoration (FLISR)





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# Next Steps- Microgrid for HPC Grid Support and Resiliency

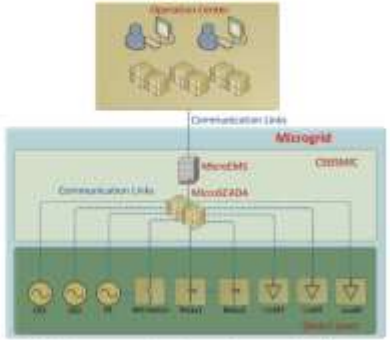
- Advantages/Impact
  - Load profile smoothing
  - Support during power system transients and events
  - Reliable transition from on-grid to islanded power supply
- HPC Microgrid would use the ORNL-CSeismic Microgrid Controller

## ORNL Microgrid Controller: CSEISMIC

ORNL has developed a Complete System-level Efficient and Interoperable Solution for Microgrid Integrated Controls (CSEISMIC). It monitors and controls the microgrid components through communication links to perform both real-time controls and energy management. It is also the interface between the microgrid and the power system operator/energy market for the microgrid to participate in system operation and/or energy market activities.

***CSEISMIC Functions:***

- On-grid operation
- Islanded operation
- Black start capability
- Automatic islanding transition
- Active resynchronization and reconnection
- Adaptive protection
- Microgrid energy management system to optimize energy profile
- Provide ancillary services
- Participate in energy market




*CSEISMIC communication and control architecture*



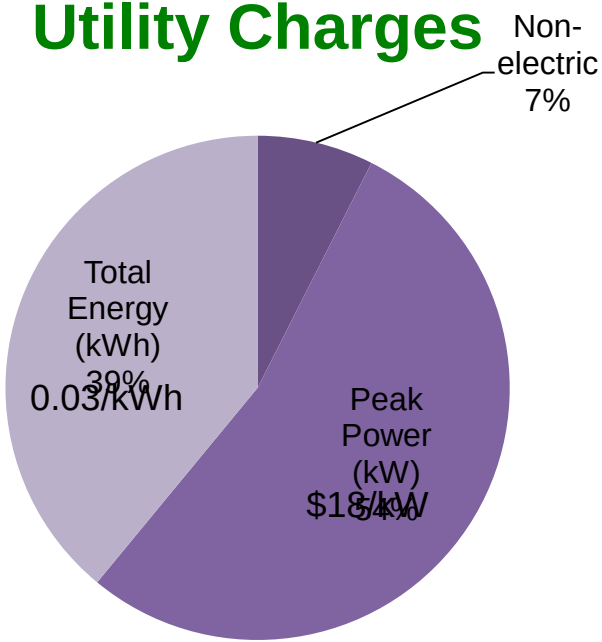


OAK RIDGE National Laboratory

# National Renewable Energy Lab

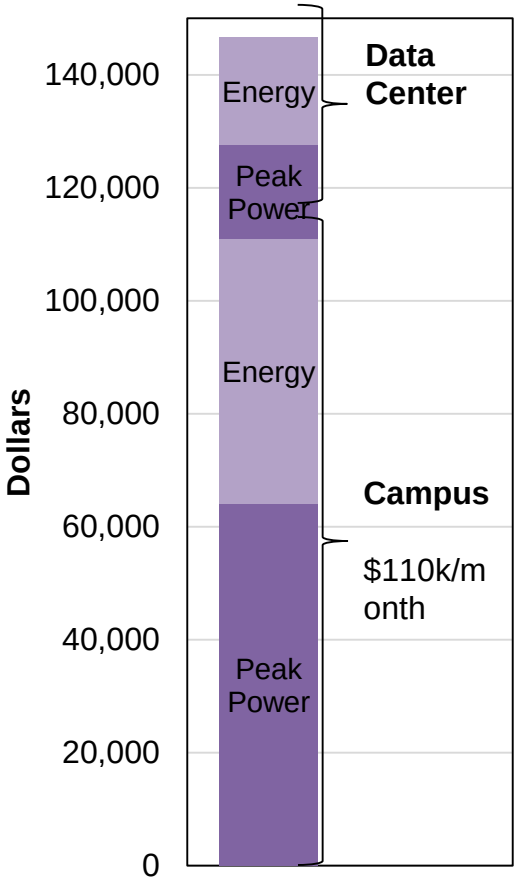
## SITE UPDATE

# Typical Monthly Utility Charges

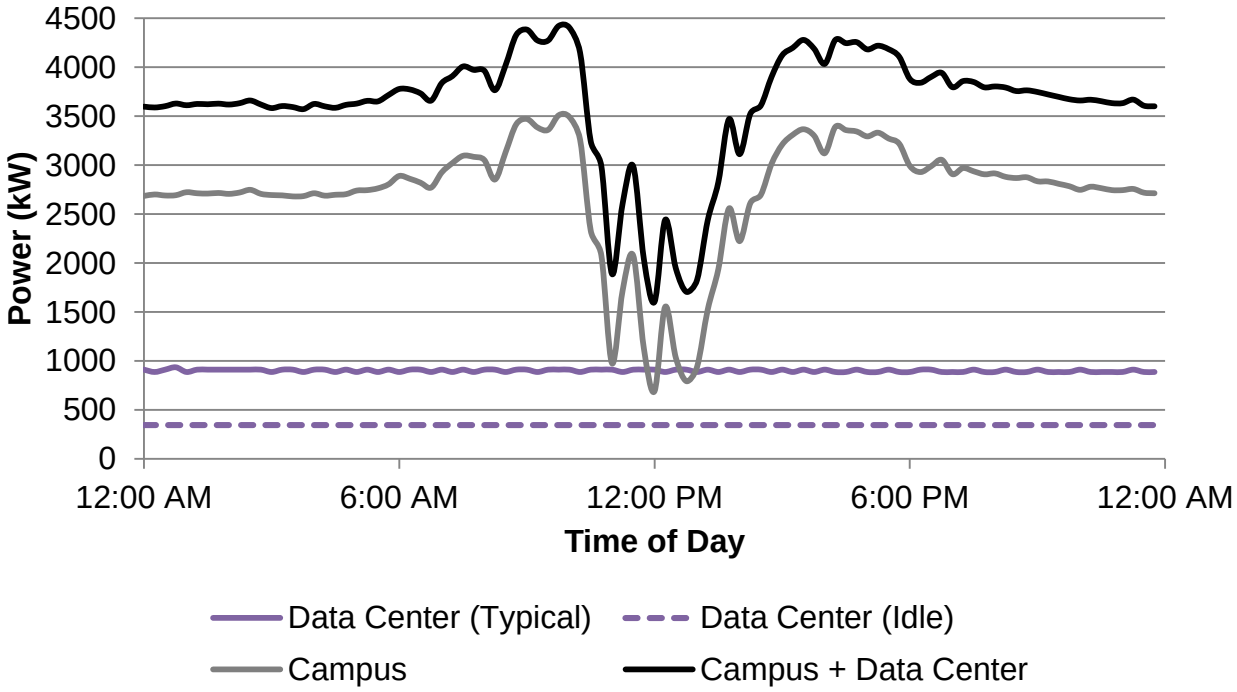


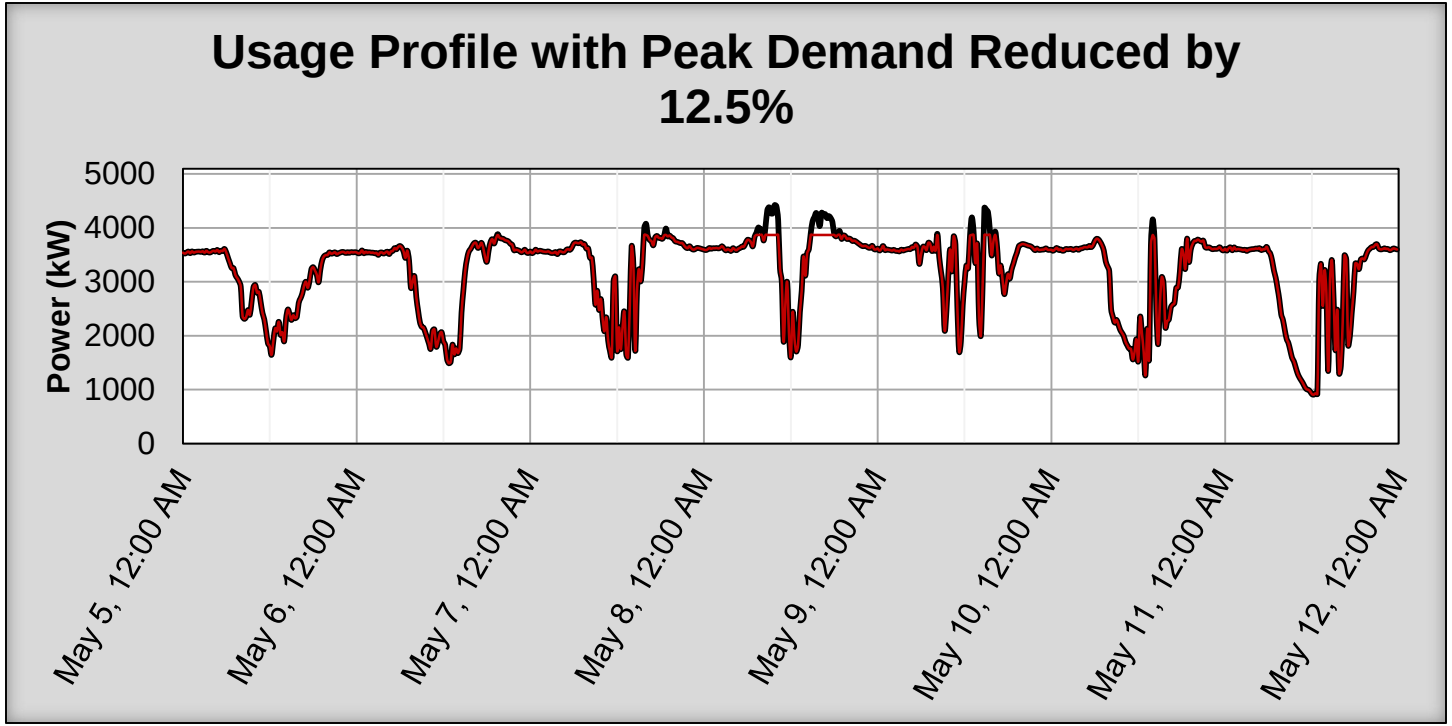

## Xcel Cost

***Typical Month***



# Electrical Usage: Campus + Data Center






*Approximate Monthly Savings $9K*

# Lawrence Livermore National Lab

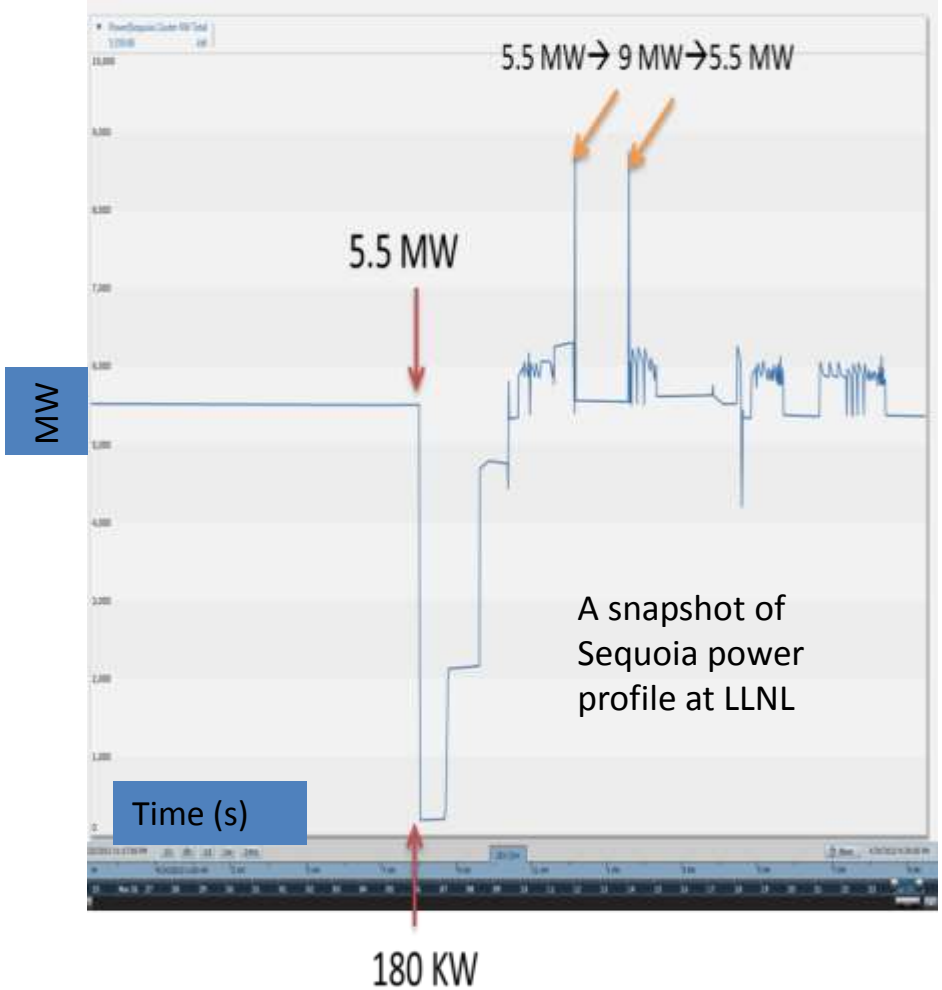
## SITE UPDATE

# LLNL Power Distribution Facts

- Most unique fact: LLNL has ramp up/down control of HPC load and provides frequent power predictions for utility based on lessons learned
- LLNL is part of Consortium with LBL and SLAC and Exeter is the energy consultant to negotiate contracts
- The Consortium has two scheduled meetings annually and meet more often as required
  - Forecast quarterly and daily when bringing on new HPC systems
- LLNL HPC Facility Operations communicates on a weekly basis to WAPA if there is a variance in the HPC load
  - Instituted HPC maintenance day on Wednesdays
  - WAPA anticipates that Wednesdays could be greater than 10MW swing
- LLNL has (2) utilities (WAPA and PG&E) tied in parallel at all times.
  - Have not lost site power since going parallel in 1998
- Cost of energy is nominally $.05/kwh - Only pay for energy without transmission, wheeling or capacity fees
- Exeter uses incentives for renewables and LLNL has a 3.9MW on-site solar plant

# LLNL Power Distribution Facts

- Penalties could exist with WAPA if the Automatic Generation Control (AGC) swings more than 10MW in the entire sub control zone of 500MW
  - LLNL is only about 5% of this AGC since load is split 50/50 (WAPA and PG&E)
  - AGC is programmed based on load forecasts and ensures ample generation is available for the anticipated load
  - AGC modulates and regulates based on real time conditions for voltage, frequency and current
- LLNL Site power = 60MW peak
- HPC power = 20MW peak
- Livermore Computing (LC) bumped the power grid while running Linpack on Sequoia 9.8MW peak - 180kw idle
  - Now LLNL performs ramp control of load through software




A snapshot of Sequoia power profile at LLNL

# Leibniz-Rechenzentrum (LRZ)

## SITE UPDATE

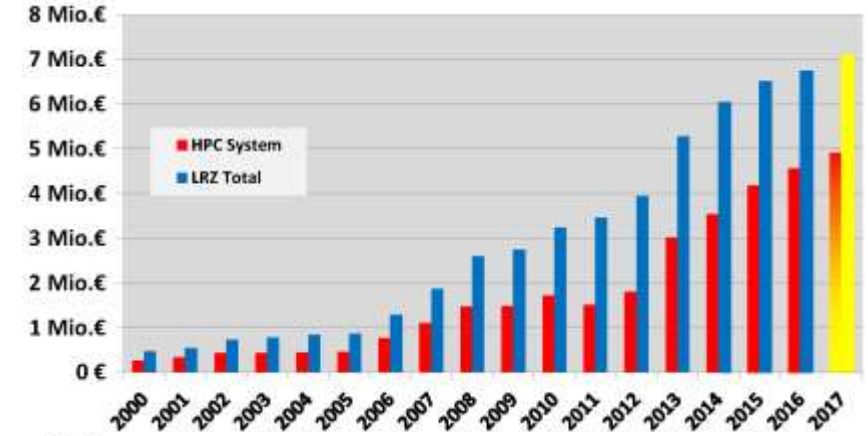
# Site Update: LRZ

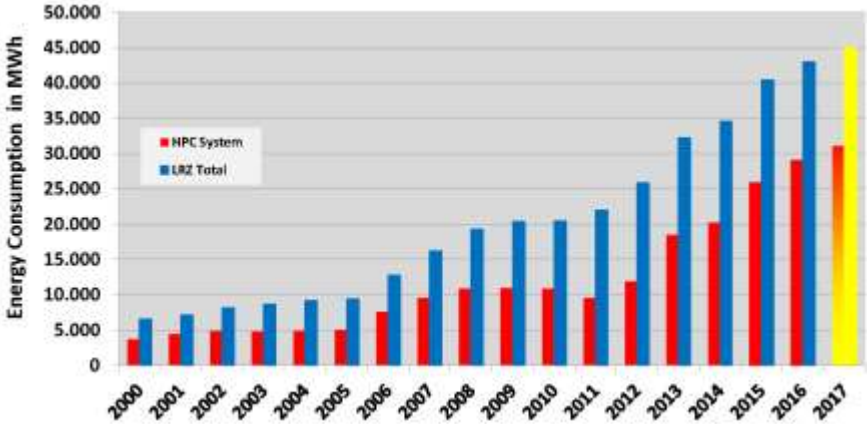
EEHPCWG annual workshop, SC‘17

**Torsten Wilde (LRZ)**

Leibniz-Rechenzentrum
der Bayerischen Akademie der Wissenschaften

# Energy Costs at LRZ




- **Costs for 1kWh:**
  - 2000 – 0.07€
  - 2015 – 0.16€

- **Better Compute efficiency but more Compute (bigger and more systems) per Money**

# Site Questions: LRZ

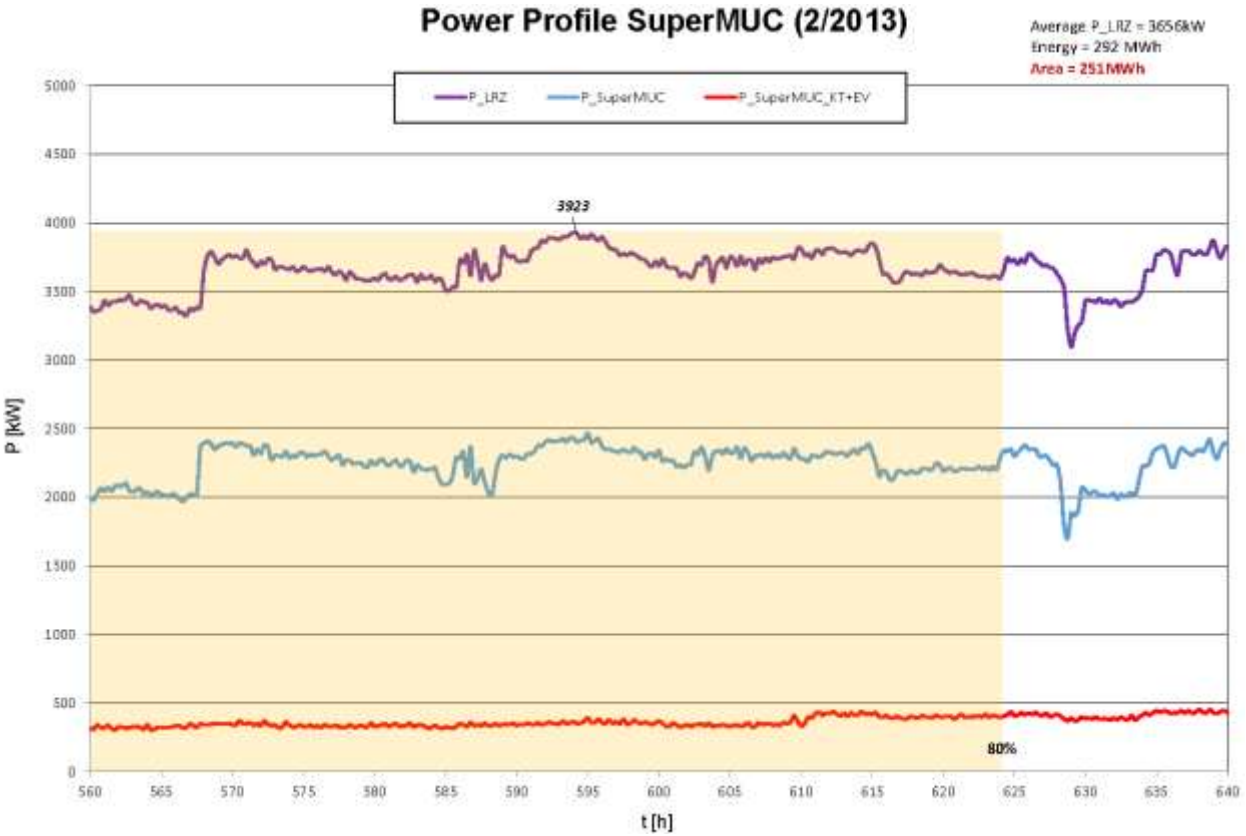
- Who at your site owns the relationship with the utility
  - Director of operations (energy needs to put into local government budget 2 years in advance)
- How often do you talk to the utility?
  - Only to communicate maintenance periods -- one-way street
- Any incentives for renewables?  Or on-site generation?
  - Power contract is for 100% renewable energy (government demanded)

# Power Contract

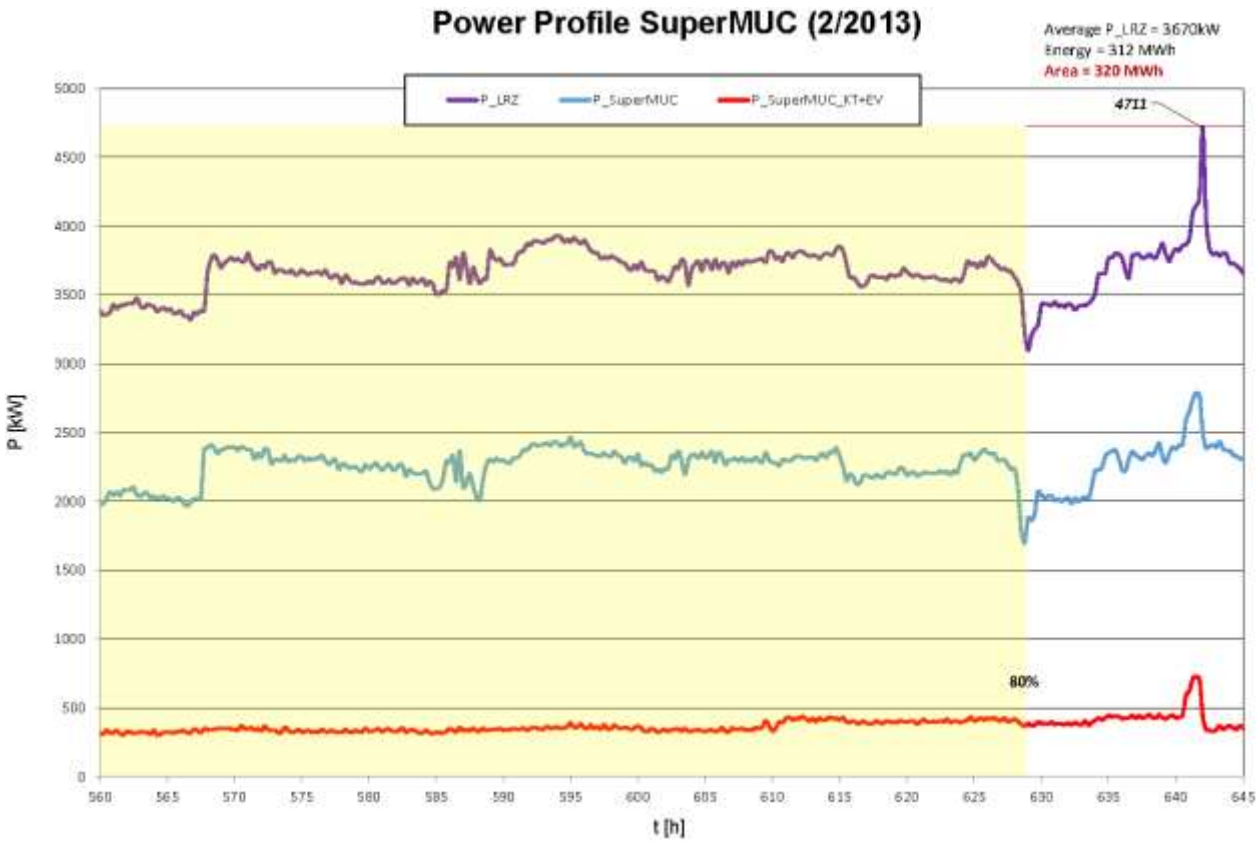
- Yearly payment consists of two parts:
  - Connection fee – Charged by the owner of the physical power lines, fixed charges per kWh
    - Can save 50% of it (≈ 250 k€)
  - Energy Costs – Charged by the power provider, price of used energy, depends on final (yearly) energy consumption (kWh)

- Biggest cost factor is Energy Consumption
  - LRZ Main Goal: Improve Energy Efficiency
    - Energy Aware Scheduling
  - LRZ Secondary Goal: Limit Power Peaks to 10% of Data Center Average Power Consumption in billing cycle (15min at LRZ)
    - Analyze past occurrences, avoid in the future (currently manually)

# Example, LRZ Power Contract 1/2



# Example, LRZ Power Contract 2/2



# Power Variability Estimates for Exascale

| | SuperMUC Phase1 | Exascale (35 MW average power) | Exascale with 100% chiller-less cooling (COP 10 to 25, overhead 10% to 4%) |
|---|---|---|---|
| Idle power | 0.7 MW | 11.2 MW | 11.7 MW to 12.3 MW |
| average power | 2.2 MW | 35.0 MW | 36.4 MW to 38.5 MW |
| max (Linpack) power | 2.9 MW | 46.2 MW | 48.0 MW to 50.8 MW |
| max (Linpack) power and cooling | 3.7 MW | - | - |
| max. power variability | 3.0 MW | | 39.1 MW |

# HPC Spa & Resort

# Los Alamos National Laboratory

## SITE UPDATE

# SC17 – Energy Efficient HPC Working Group

## Power Supply Accommodations for Computing Load Growth

**Grant L. Stewart, PE**

Utility Operations - Project Director

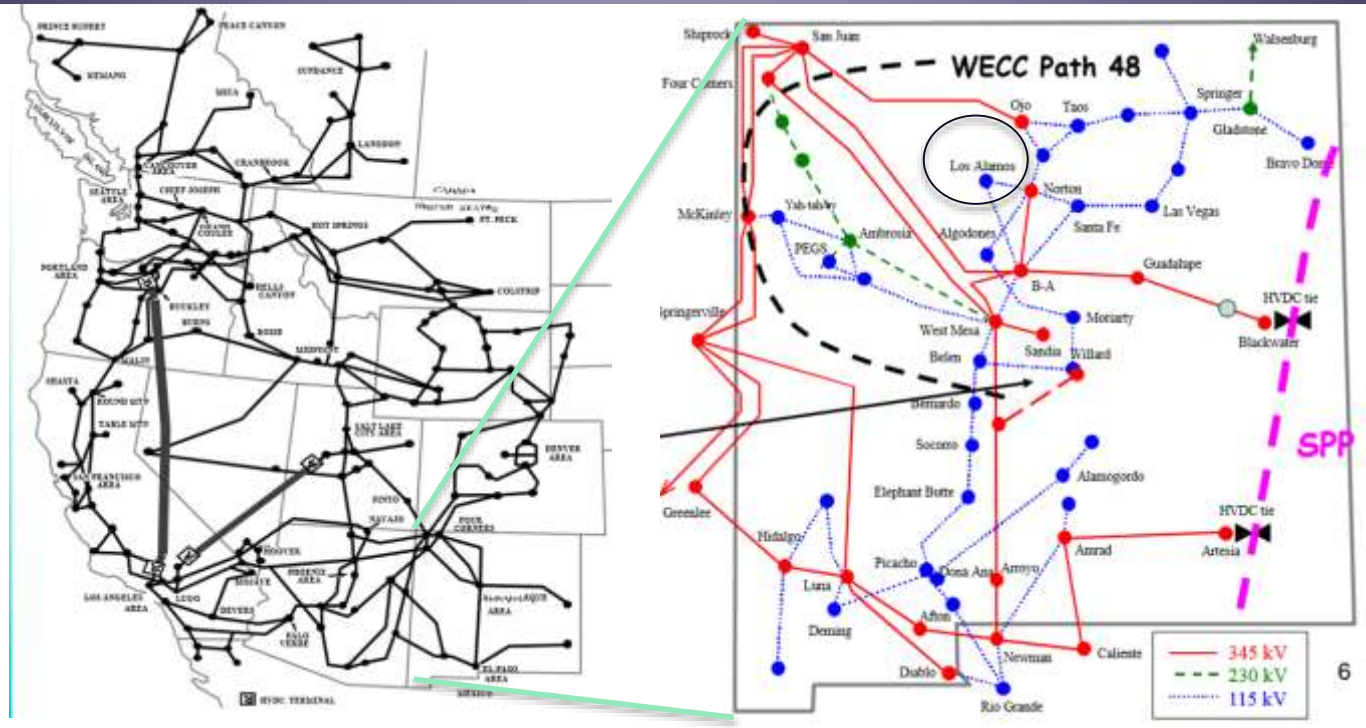
November 12, 2017

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

- **Power Grid**
  - Transmission Grid
  - Distribution Grid
  - LANL's Grid Connection
- **Demand Growth, Power Quality & Grid Stability**
  - Demand Forecast
  - Demand Fluctuation
  - Power Quality & Grid Stability
  - Distribution Stiffness

# Power Grid

# Transmission Grid




***LANL is connected to the Western Grid by two 115KV lines***

# Transmission Grid

- **Power import to LANL is limited to the lowest capacity of either of two transmission lines**
  - NL (116 MVA peak summer limit)
  - RL (131 MVA peak summer limit)
- **LANL's most recent peak-hour demand exceeded 90 MVA**
- **Load is projected to increase to a peak-hour demand of 160 MVA by 2025**
- **Planning underway to increase the import capacity to > 200 MVA with a capital line-item project**
- **Planning also underway to improve on-site generation up to 45 MVA.**

***LANL's grid connection is robust and improving***

# Distribution Grid

## LANL Strategic Computing Complex (SCC)

- Two import transmission lines feed five interconnected substations
- Multiple substations feed each switch gear
- Each switch gear is connected to at least one other by inter-tie circuits
- Five underground, distribution feeder circuits (10 MVA capacity each) connect SCC to major substations through two separate switch gear
- Within SCC, feeder circuits supply switchable power stations serving eleven load centers
- Load centers serving compute load have double ended buss with independently supplied transformers and automatic switching capability

***Redundant flow paths allow for operation through maintenance evolutions***

# LANL's Grid Connection

## What's unique about LANL's grid connection?

- Peak demand charges - highest monthly hour (hour of the day varies)
- No charges for power factor correction
- Interconnection allowance for +/-2 MW variance from scheduled demand (without penalty, average over the hour)
- FY2017 average power cost for LANL was $52/MWHr (includes power purchase, transmission, and on-site operations)
- Total consumption was 420 GWhrs

# LANL Grid Connection

## What's unique about LANL's grid connection?

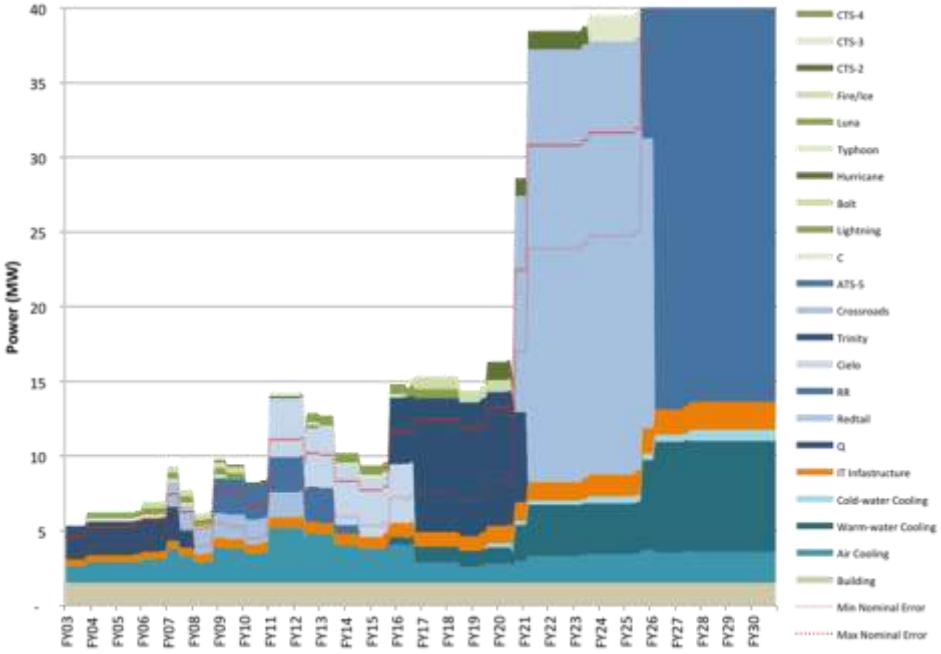
- **WECC/FERC registered Transmission Operator (TO/TOP)**
- **Installed +135/-46 MVar Static VAR Compensator (SVC) on 115 KV buss**
- **Installed extensive shunt capacitor banks**
- **On-site generation with voltage regulation (20-27 MW gas turbine)**
- **Cost sharing partnership with county utility includes**
  - Ownership of hydro power, coal-fired, and photovoltaic generation
  - Staff a merchant desk for power and natural gas transactions
  - Have network interconnection agreement with adjacent IOU (i.e., market access - purchase or sell excess power)

***Fully functional power utility***

# Demand Growth,
# Power Quality, Grid Stability

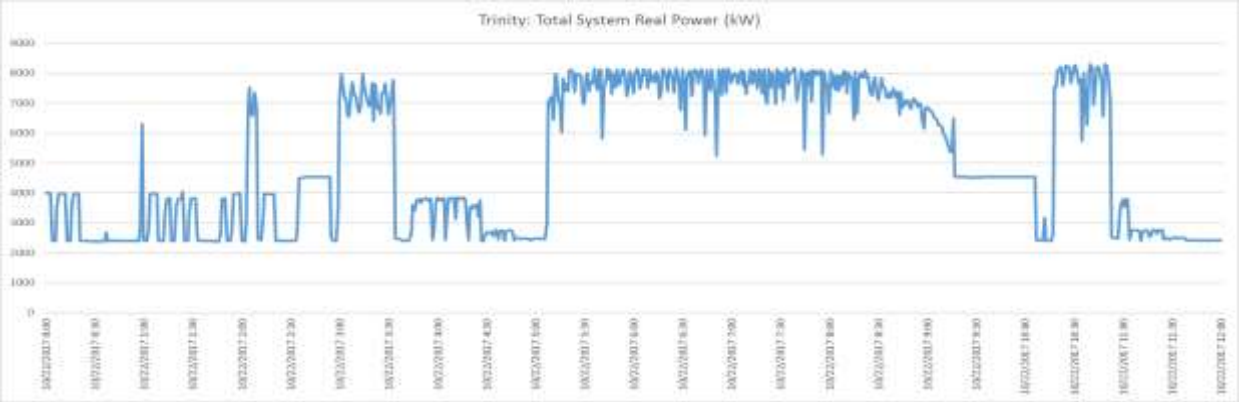
# LANL Computing Power Demand Forecast

- Projections for peak power require >40MW in the 2025 timeframe
- Future Supercomputing Infrastructure Project is looking at how best to provide increased power for supercomputing starting in 2025




***With power demand comes cooling water demand***

# Trinity Demand Fluctuation (15 sec & 1 hr time step)



# Power Quality & Grid Stability

- **Disturbances are rapid changes in power flow that produce voltage fluctuations**
- **Voltage fluctuations >5% can cause motors to stall, and damage various connected equipment**
  - Local disturbances in the distribution system (<15KV) are mitigated by distance/ impedance (localized impact)
  - Large external disturbances propagate from transmission into whole distribution system (system-wide impact)
- **The ability of the grid to ride through disturbances is "stiffness"**
- **A grid with insufficient voltage support resources can become unstable (voltage does not quickly return to equilibrium)**
- **Utilities invest in equipment to improves stiffness and discourage large customers from producing disturbances**

***Trinity demand pattern has not caused widespread voltage fluctuation***

# LANL Distribution Stiffness

- Cross Roads and ATS-5 machine, power demand fluctuation could cause wider-spread voltage fluctuation
- Many options available to address potential concern
- Understanding these future conditions requires time-dependent dynamic analysis
- LANL has selected ETAP modeling software for distribution system dynamics and GE PSLF for transmission system dynamics

***Time-dependent analysis required***

Ben Kroposki
NREL
IEEE Fellow

# WHAT YOU NEED TO KNOW ABOUT THE POWER GRID BEFORE ADDING A 10 MW STEP-FUNCTION LOAD GENERATOR

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Power Systems
Engineering Center

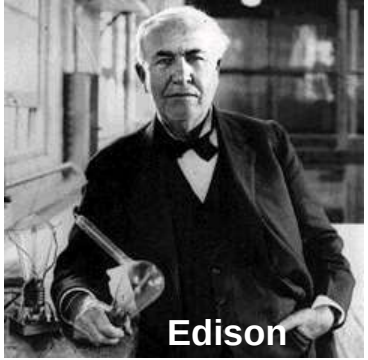
# Power Systems Basics
## What you need to know

**Ben Kroposki, PhD, PE, FIEEE**

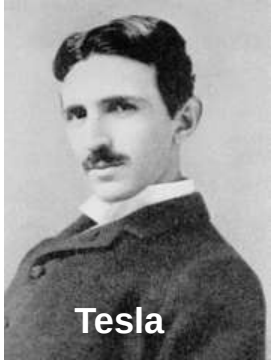
Director – Power Systems Engineering Center

https://www.nrel.gov/grid/

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.



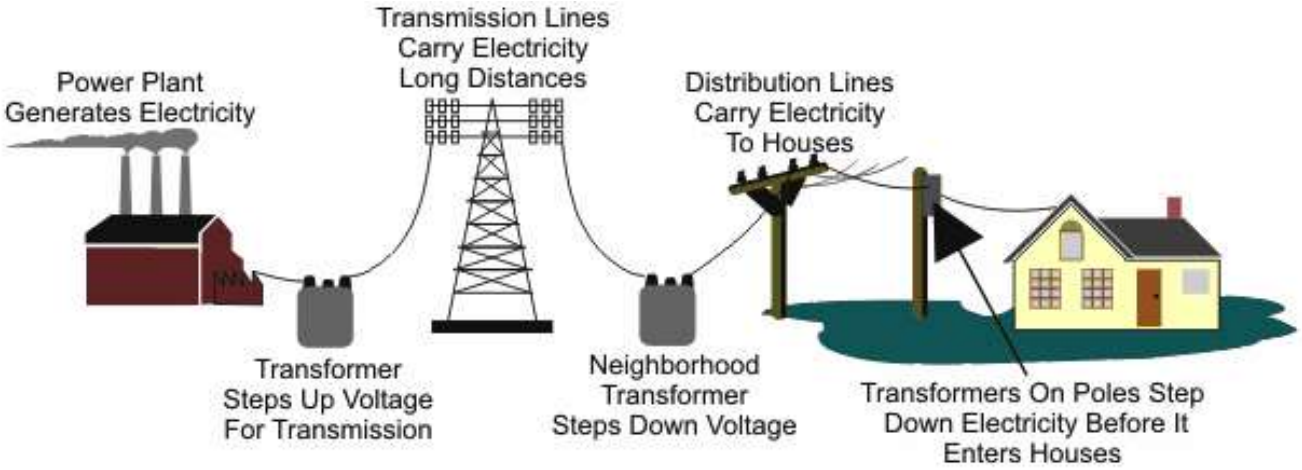

# Early History of Electric Power




- Early 1880's – Edison built Pearl Street direct current (DC) system in New York supplying 59 customers.
- 1884 – Sprague produces practical DC motor.
- 1885 – Invention of the transformer.
- Mid 1880's – Westinghouse/Tesla introduce alternating current (AC) system.
- Late 1880's – Tesla AC induction motor refined.
- 1893 – First 3-phase transmission line operating at 2.3 kV.
- 1896 – AC lines deliver electricity from Niagara Falls hydro to Buffalo (25 miles, 25Hz, 2-phase, 11kV, 37MW of power)

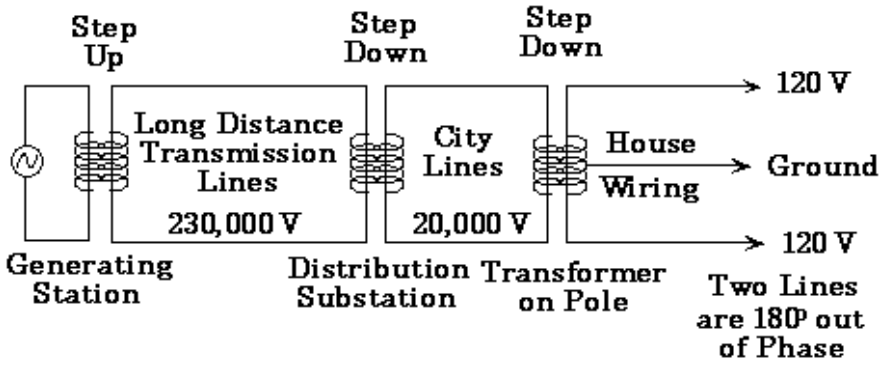
# Electric Grid

Connects power generation with power consumption through a vast network – humanity's "most significant engineering achievement of the 20th century".



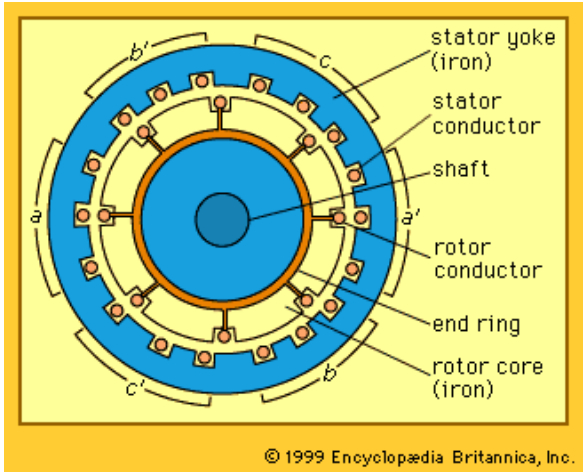
# Why Use AC for Transmission?

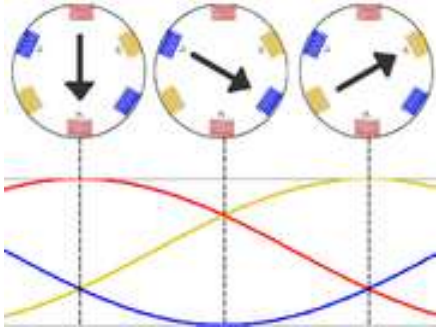
- Power loss along a transmission line is given by $P = I^2R$, $I = P/V$, where I is the current through the line and R is the conductor's resistance
- R depends on the type of material being used for the transmission line (originally copper, now primarily aluminum) and the length of the transmission line
- Invention of the transformer allowed AC to be stepped up and down in voltage. Power companies convert alternating current to very high voltages for transmission (115kV-765kV), then drop it back down to lower voltages for distribution (such as 15kV volts), and finally down to 120/240 volts inside the house for safety.
- AC systems can have multiple phases, allowing for reduced number of conductors in balanced three-phase systems.



# Induction Motor – Another Reason for AC

- The induction motor with a wrapped rotor was invented by Nikola Tesla in 1882.
- Current is supplied onto the rotor which creates a magnetic field through magnetic interaction and links to the rotating magnetic field in the stator which in turn causes the rotor to turn. It is called synchronous because at steady state the speed of the rotor is the same as the speed of the rotating magnetic field in the stator.
- To achieve this, stator windings are arranged around the rotor so that when energized with a polyphase supply they create a rotating magnetic field pattern which sweeps past the rotor. This changing magnetic field pattern induces current in the rotor conductors. These currents interact with the rotating magnetic field created by the stator and cause a rotational motion on the rotor.

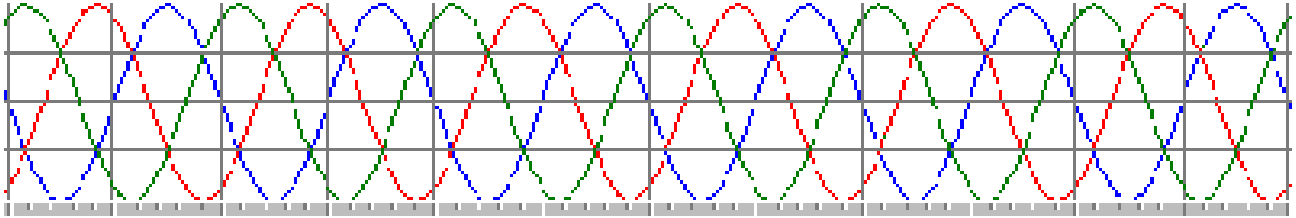


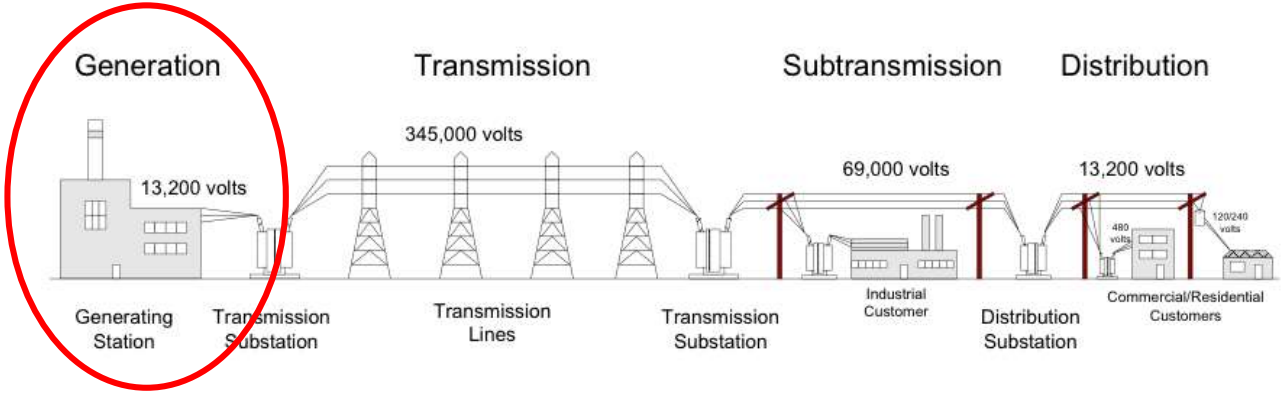
**A 3-phase power supply provides a rotating magnetic field in an induction motor.**

# Electric Grid – Power Generation

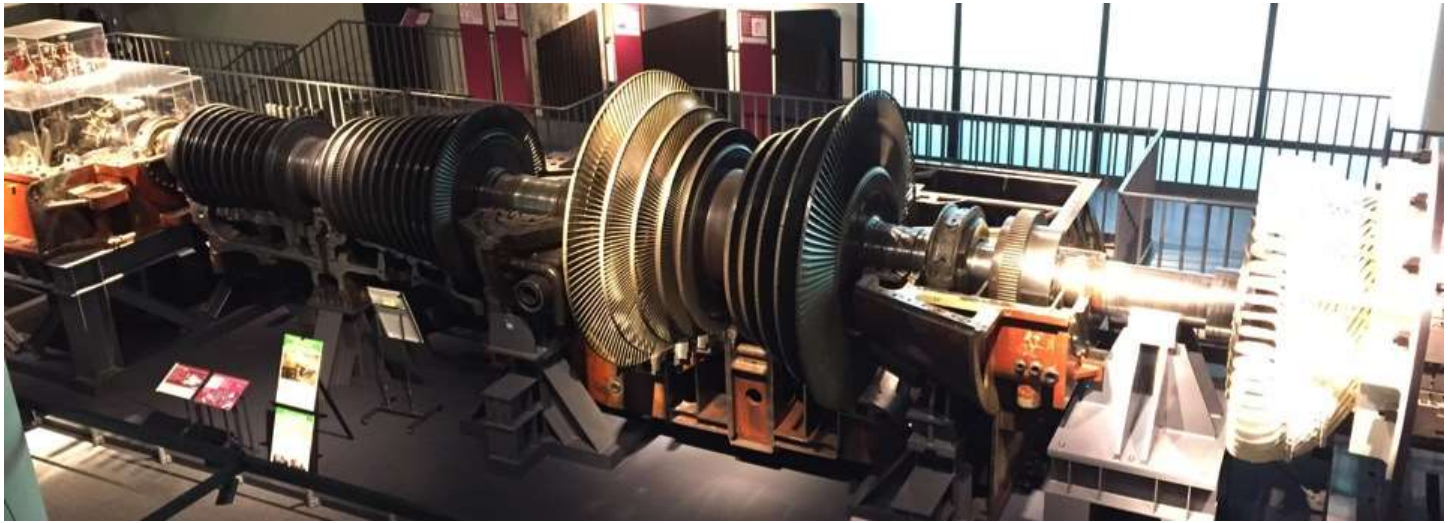
- Commercial electric generators produce 3-phase AC power (synchronous generators).
- The three phases are offset by 120 degrees from each other. Three phases allows that at any given time, one of the phases is nearing its peak. Could go to 4 phases or higher, but then need to have more wires.



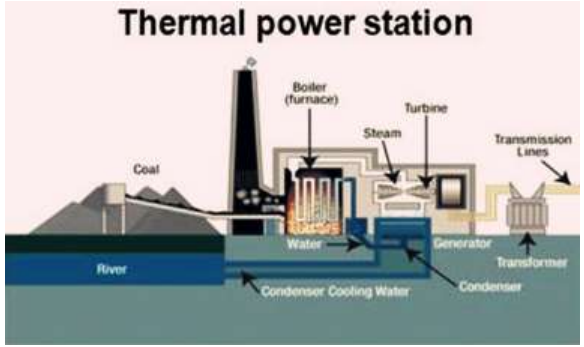
- There are four cables coming out of every generator (often shown schematically as 3) – cable for each of the three phases and a neutral or ground, common to all three. Electricity transmission uses the Earth as the ground (often shown schematically as 3 wires) .

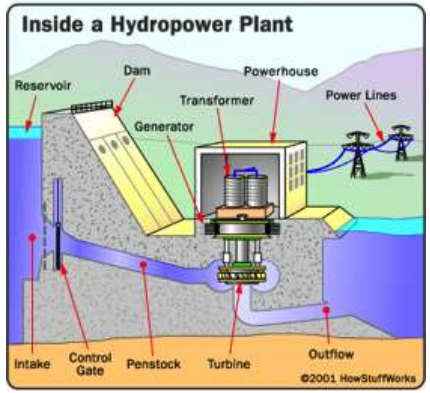


# Electric Grid – Synchronous Generators

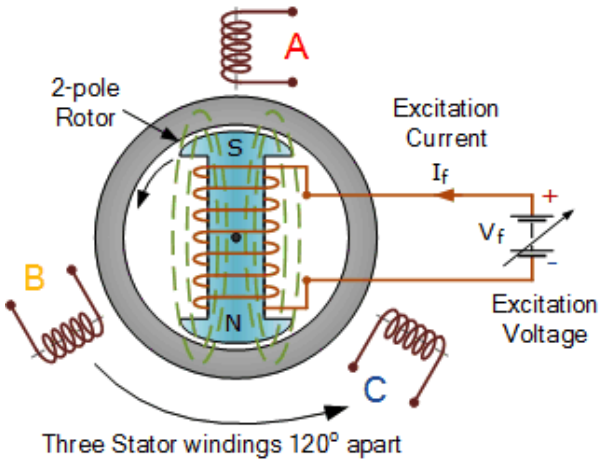


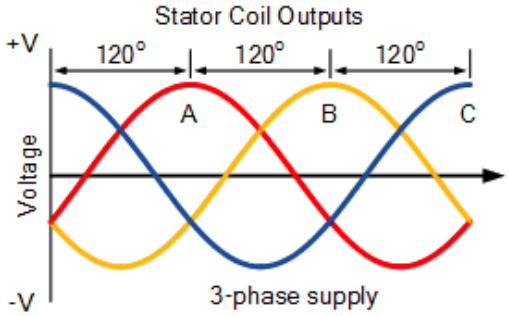
Inside a 130MW synchronous generator



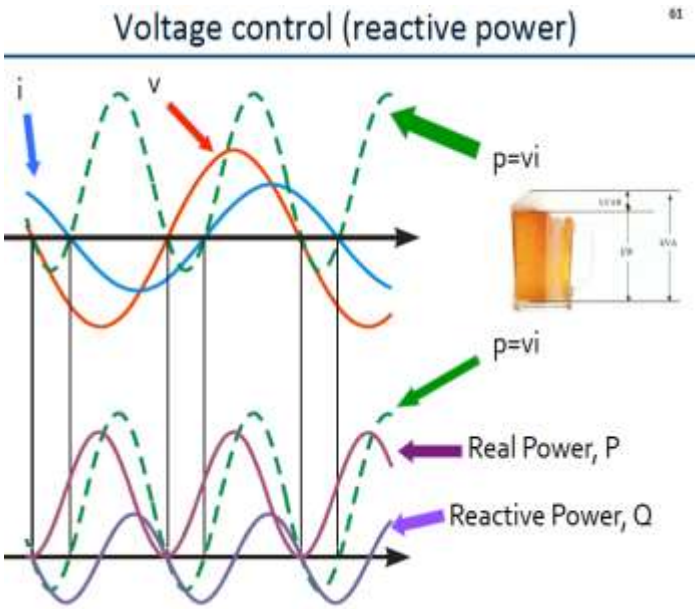
# 3-Phase Power



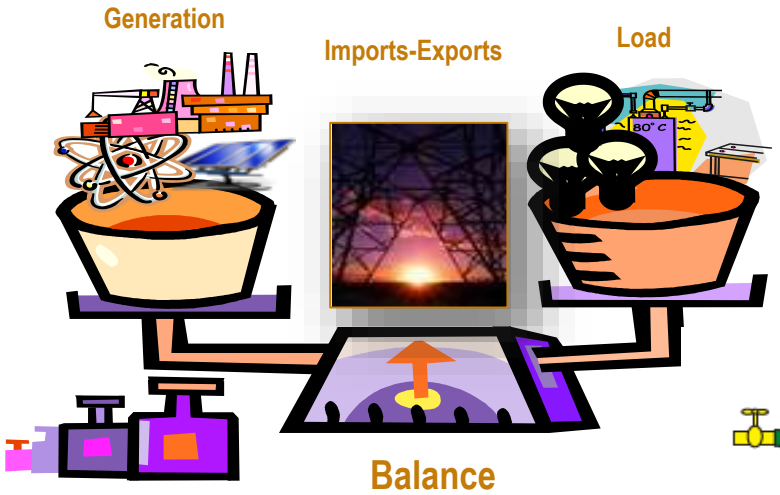

- Three phase is generated by a generator with three sets of independent windings which are physically spaced 120 degrees around the stator.
- Voltages are labeled phase A, phase B, and phase C and are the same magnitude but differ in phase angle by 120 degrees.
- Benefit - Smooth torque on generator shafts
- Delivery of constant power to a 3 phase load
- 3 wires and not 6

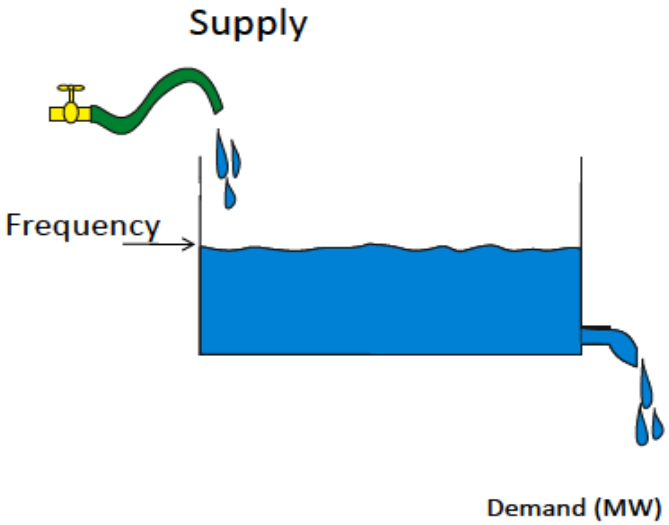
# Real and Reactive Power



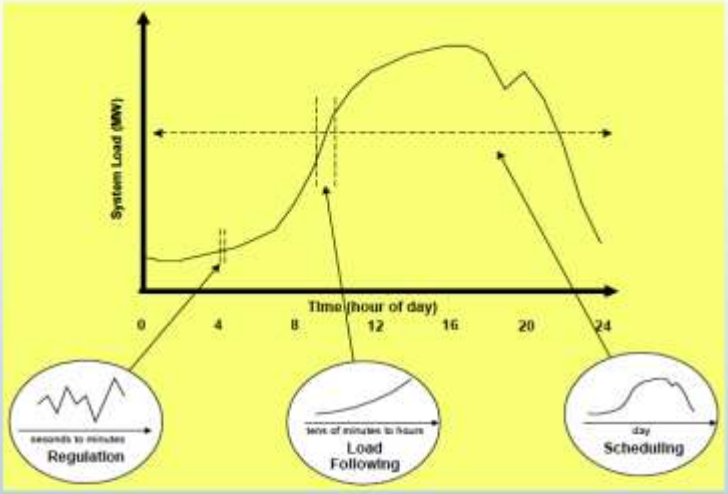

- Instantaneous power may flow in both directions
- Instantaneous power may be broken up into two components:
- Real Power only flows in one direction, its average value is zero or positive
- Reactive Power always oscillates in one direction and then reverses an equal amount. Its average value is always zero.

# Power System Stability



# Power System – Meeting the Load




## Typical U.S. terminology

- Regulation -- seconds to a few minutes -- similar to variations in customer demand
- Load-following -- tens of minutes to a few hours -- demand follows predictable patterns, wind less so

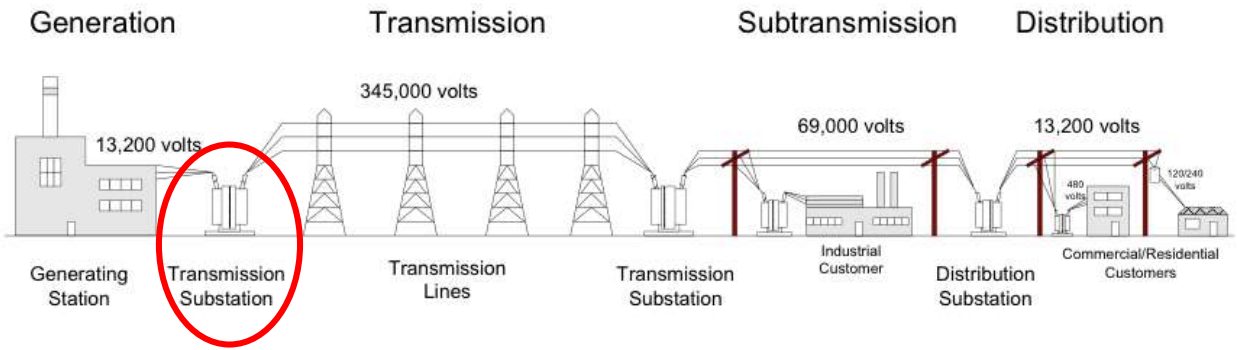
- Scheduling and commitment of generating units -- hours to several days -- wind forecasting capability?

# Where is the Power Generated Now in the U.S. and From what Sources?

- The U.S. operates a fleet of ~19,000 power plants with an average thermal efficiency of 33%.
- 240,000 miles of High voltage lines, 56,000 distribution facilities.
- 2016 Energy Numbers:
  - 33% Coal, 33% Nat Gas, 20% Nuclear, 6% hydro, 7% wind/solar
- Transmission losses are estimated to be ~7% (EIA.gov)
- Generating capacity **1164 GW**, run with a average capacity of ~45%
- The majority are >30 years old.
- Transmission line installation has lagged electrical demand. By 2025 expect need for another 7,000 miles.

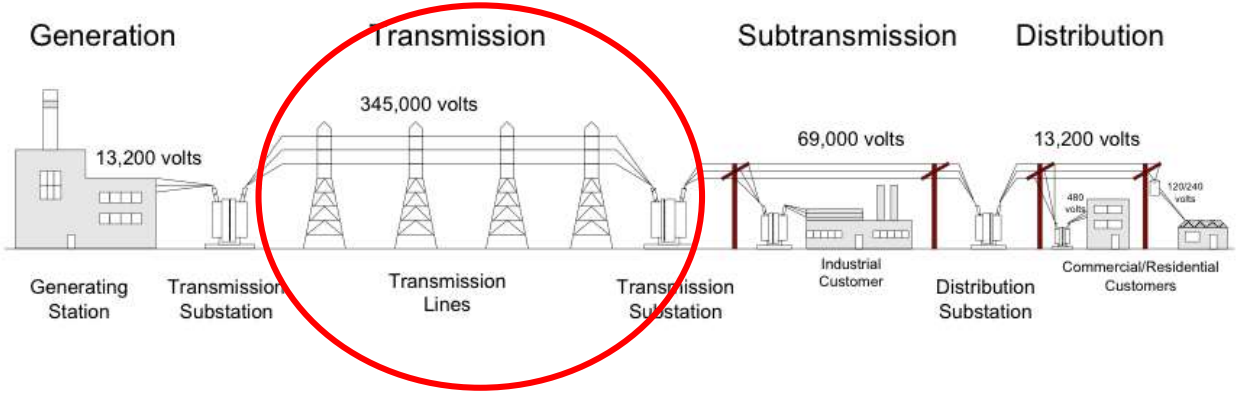
# Power Transmission
# (Step Up Transformer)

3-phase electric power leaves the power generator at the generating station and enters a transmission substation at the station that uses large transformers to convert the generator's voltage (generally 1000's volts) to extremely high voltages (115kV to 765 kV).



# Electric Grid – Power Transmission

- The transmission network moves power long distances.
- Typical voltages are 115 – 765 kV; high to reduce line losses.
- A maximum transmission distance is about 480 km (~300 miles) – in long zones series capacitors and phase-shifting transformers are used to improve phase stability.
- Longest cost-effective distance for electricity transmission is ~7,000 km (4,000 miles).
- HVDC cables sometimes used for lengths over 450 miles
- Cables may be overhead or underground.
- Transmission losses in US are about 7%.



# Major Differences between Transmission and Distribution Systems

Size and scale
Operation is fundamentally different
- Transmission system is operated actively
- Distribution system is operated passively

## Transmission Voltage Levels

115 – 765 kV

## Distribution Voltage Levels

Medium Voltage
4.16 kV
6.9 kV
13.2 kV
25 kV
34.5 kV
46 kV
69kV - Subtransmission

## Service Voltage Levels (in U.S.)

Low Voltage
480 V (3-phase) - commercial
120/240 V (single-phase) - residential

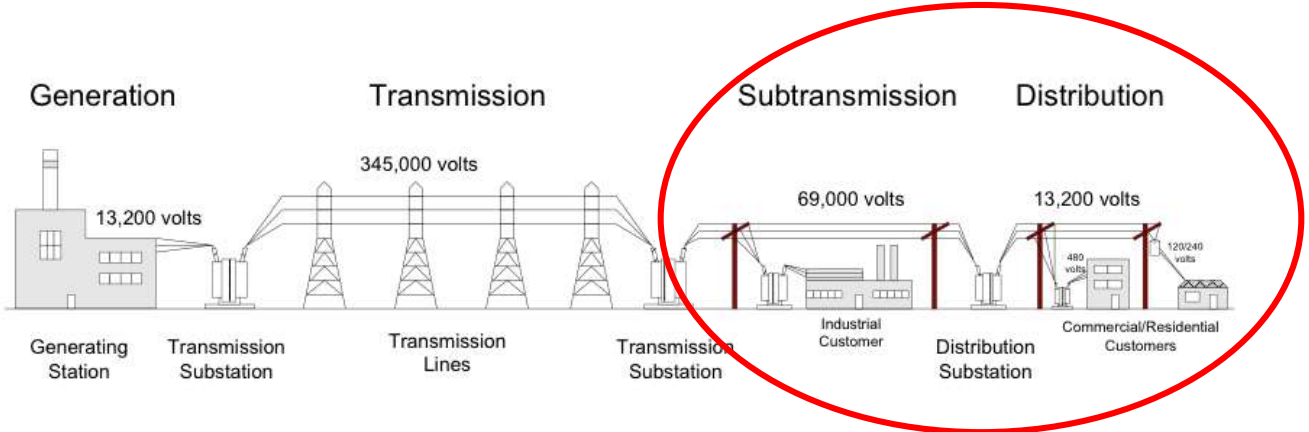
# The Substation
# Connection between Transmission and Distribution –

Power Transformer

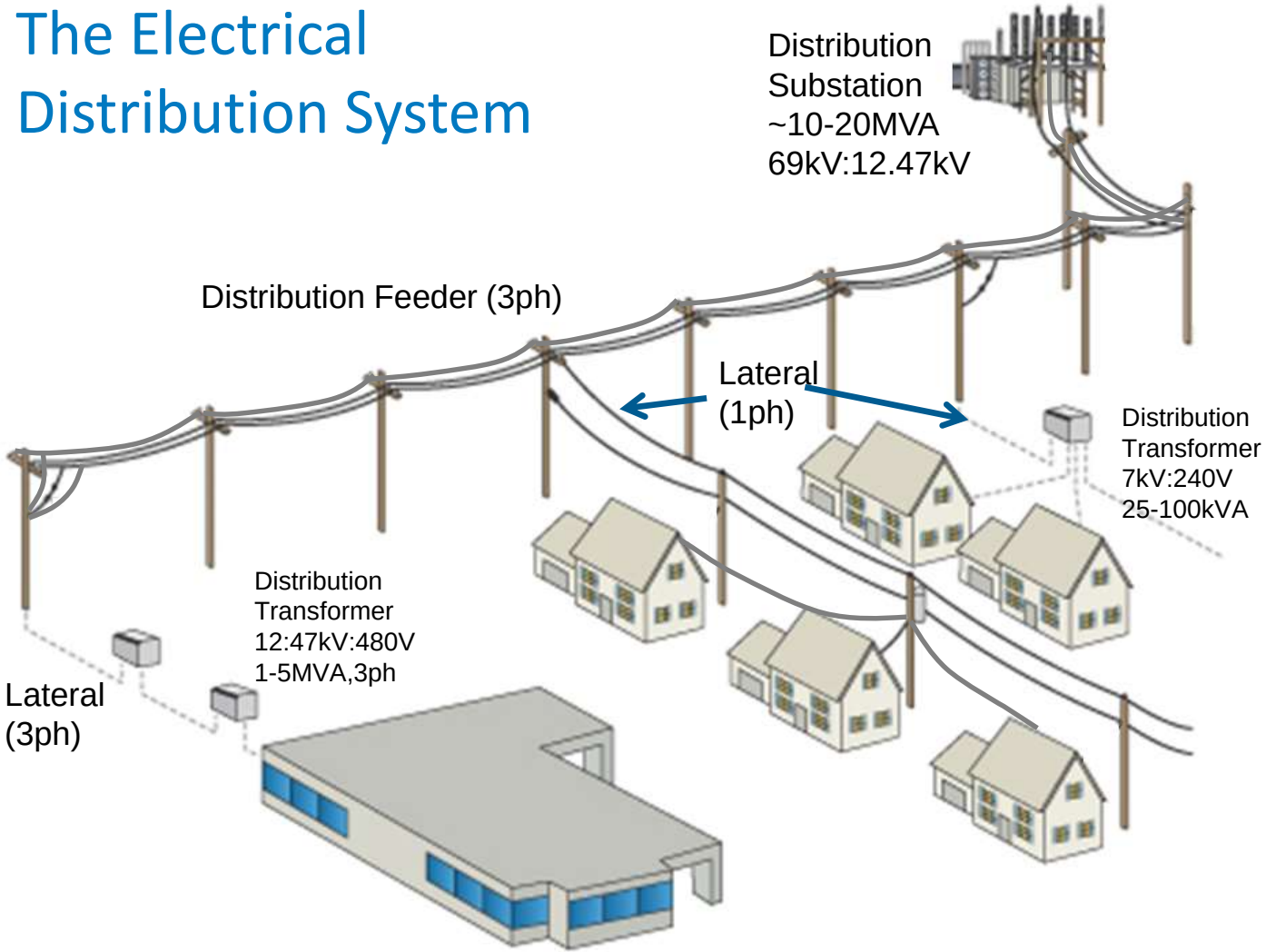
Substation

# Electric Grid – Power Distribution

- For power to be useful in businesses and homes it must be stepped-down in voltage into a distribution grid.
- Stepping down occurs in a power substation that:
  - Has transformers that reduce voltage
  - Has a “bus” that can split the distribution of power into several different lines.
  - Has circuit breakers and switches so that the substation can be disconnected from the transmission grid or separate distribution lines can be disconnected from the substation.

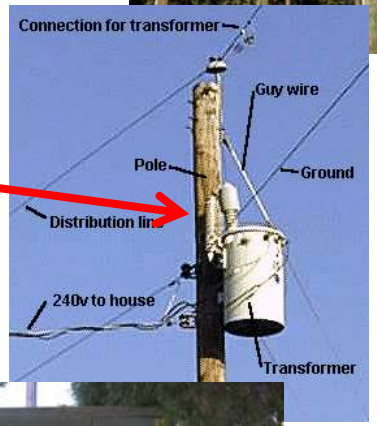


# The Electrical Distribution System



# Electric Grid – Power Distribution

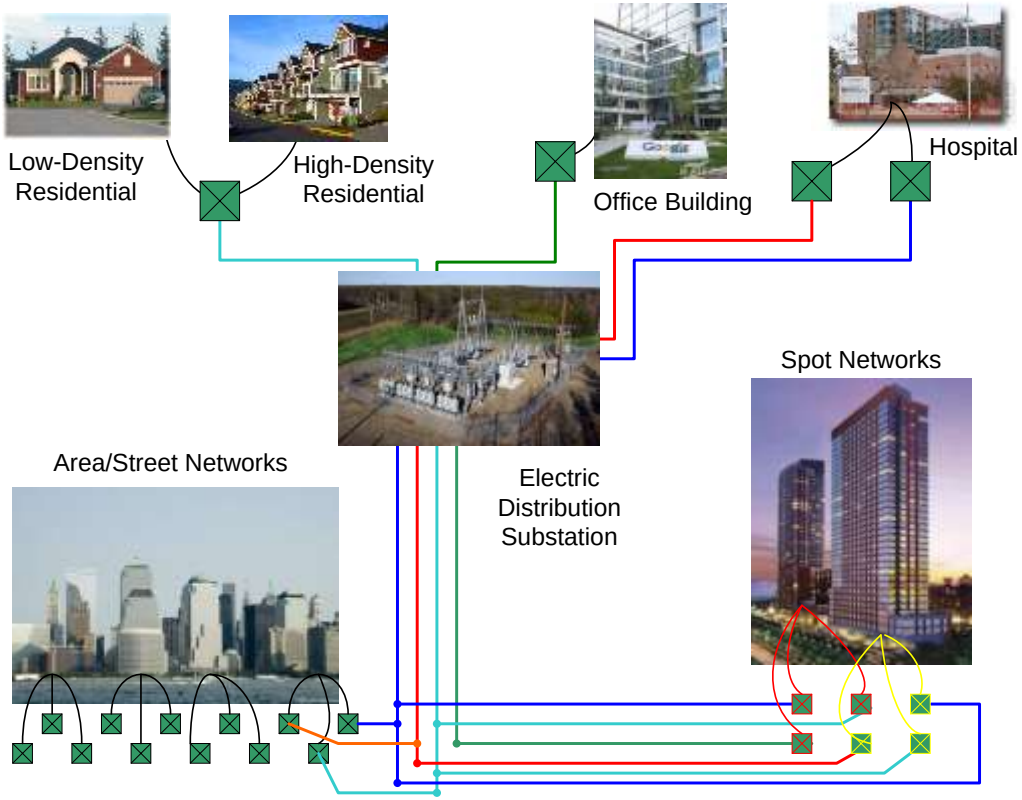
- Voltage regulation is done by load-tap changers (LTC) on transformers, voltage regulators, and capacitor banks.
- A set of poles running past a typical house has one phase of power (at 7,200 volts) and a ground wire (although sometimes there will be two or three phases on the pole, depending on where the house is located in the distribution grid).
- At each house, or cluster of houses, there is a transformer drum attached to the pole which steps down the power to 240 V.
- There are two wires running out of the transformer and three wires running to the house. The two from the transformer are insulated, and the third one is bare. The bare wire is the ground wire. The two insulated wires each carry 120 volts, but they are 180 degrees out of phase so the difference between them is 240 volts. This arrangement allows a homeowner to use both 120-volt and 240-volt appliances (120 is phase to neutral; 240 is phase to phase)
- Commercial and industrial sites are fed using 3-phase power



Three-Phase Pad-mount (13.2kV to 277/480V)

http://science.howstuffworks.com/power9.htm

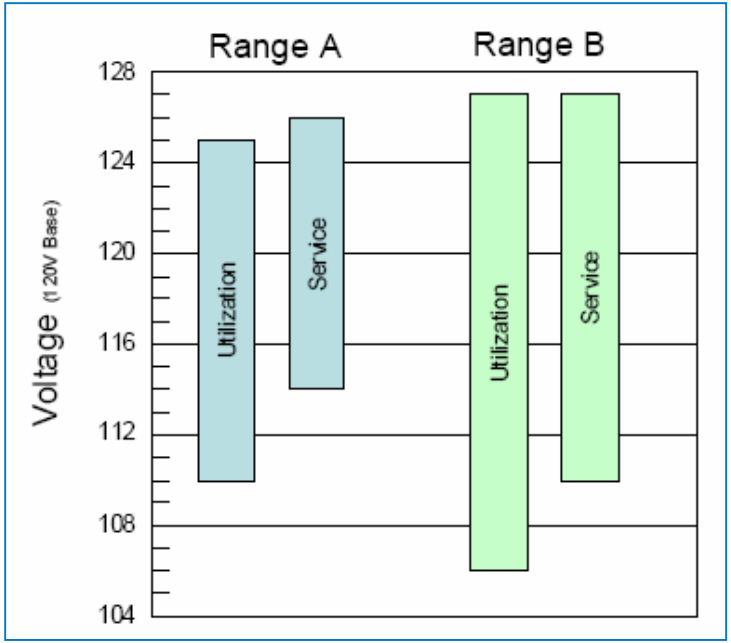
# Electric Distribution System Types



# What do you need to know when adding a large HPC system to the Grid?

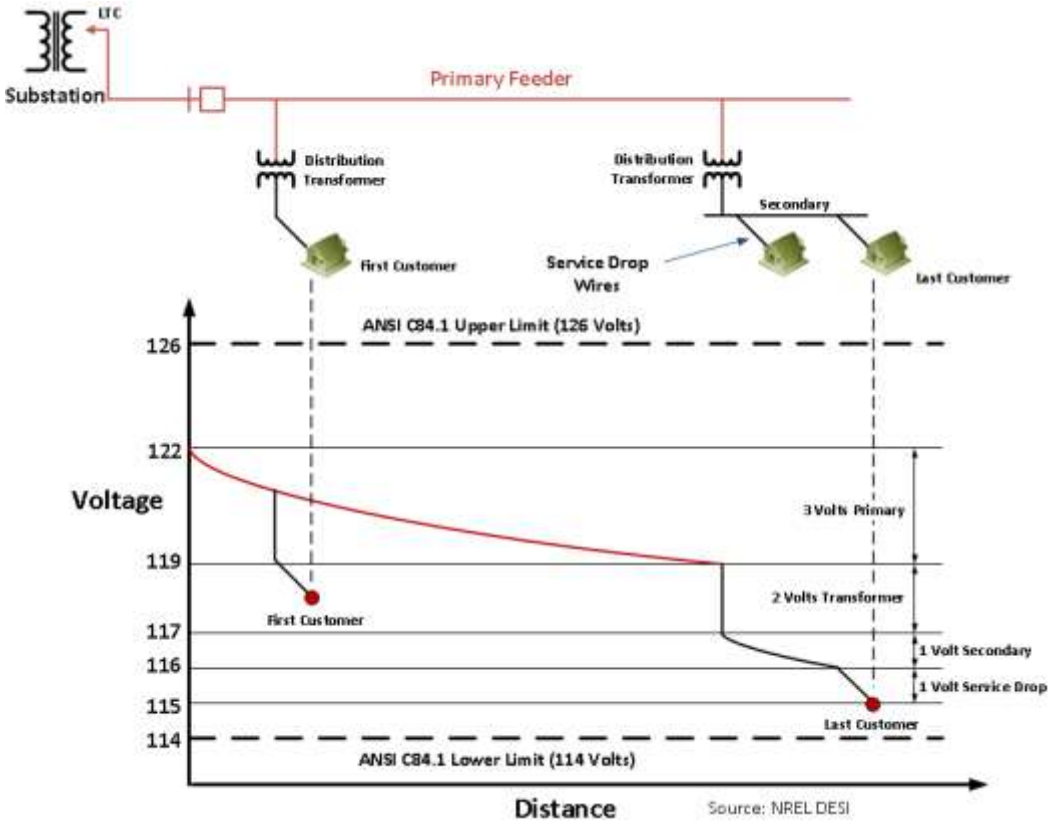
# Major concerns for utilities regarding loads

- Voltage Regulation
- Voltage Flicker
- Harmonics
- System Protection



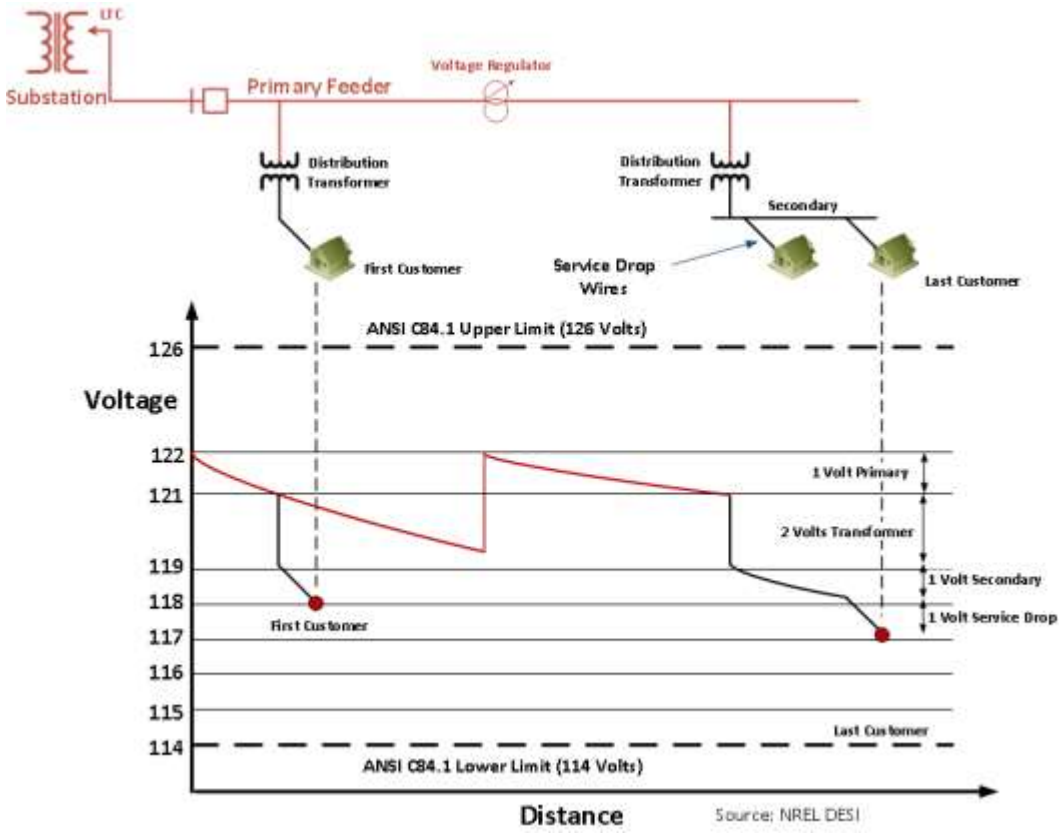

ANSI C84.1-1995 American National Standard for Electrical Power Systems and Equipment-Voltage Ratings (60 Hz)

# Traditional Distribution Voltage Drop

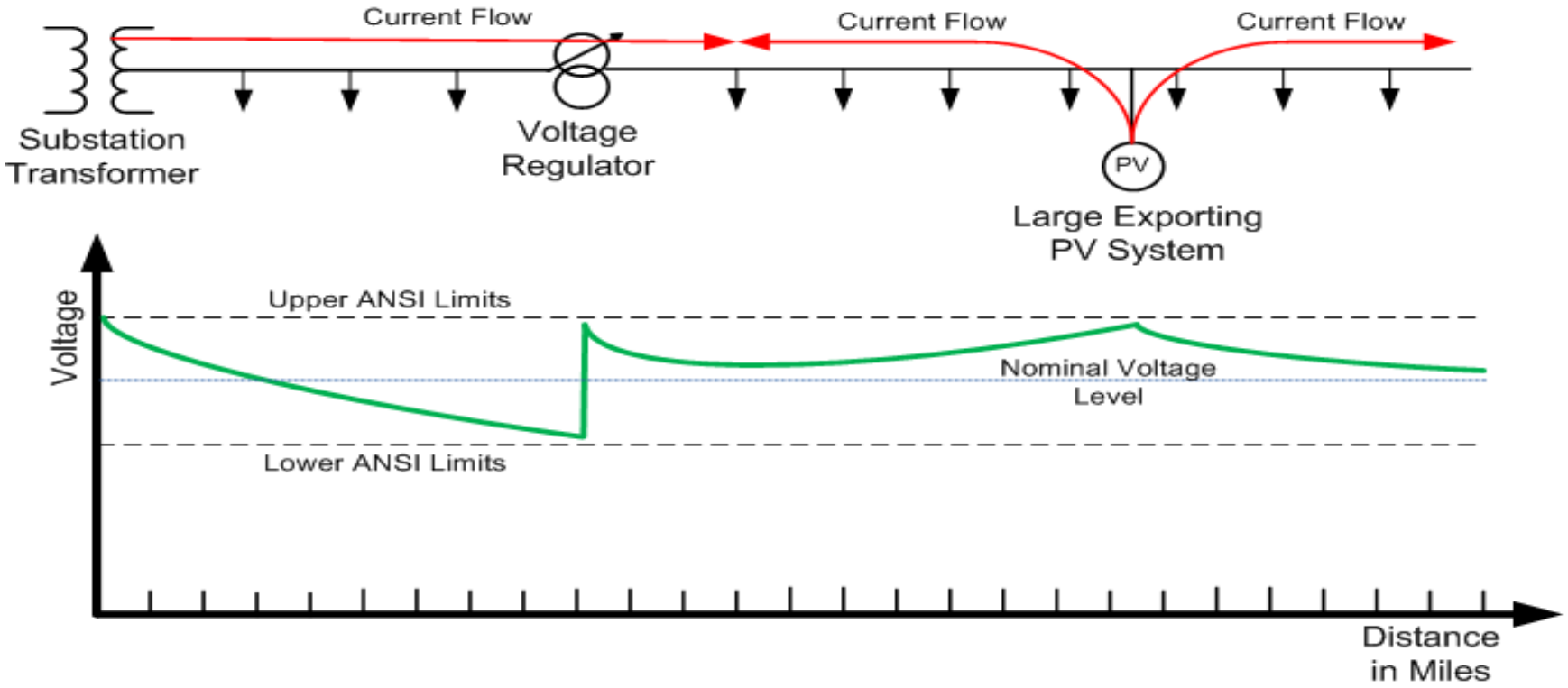



Source: NREL DESI

# Voltage Drop with Voltage Regulator

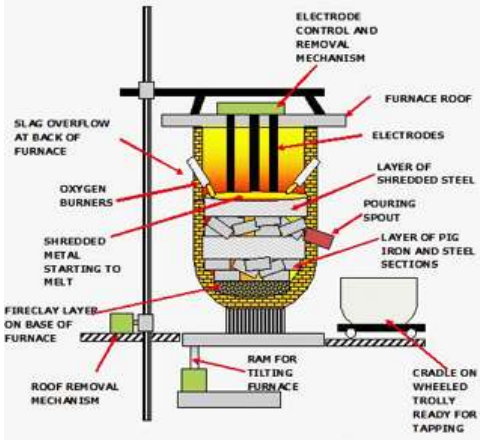


# Distribution System Voltage Profile w/ PV



# Large Loads – Electrical Arc Furnace

- Heats material using electrical arc
- Up to 400 ton for steel making
- Electrical arc of 3000°C
- 60MVA transformer
- 400-900V, 44kA
- Since they are heavy electricity uses, typically designed to run off-peak hours




Source: https://www.l-3.com/private/pacific_crest/articles/Electric%20Arc%20Furnaces.pdf

# Power Cycle of an Arc Furnace

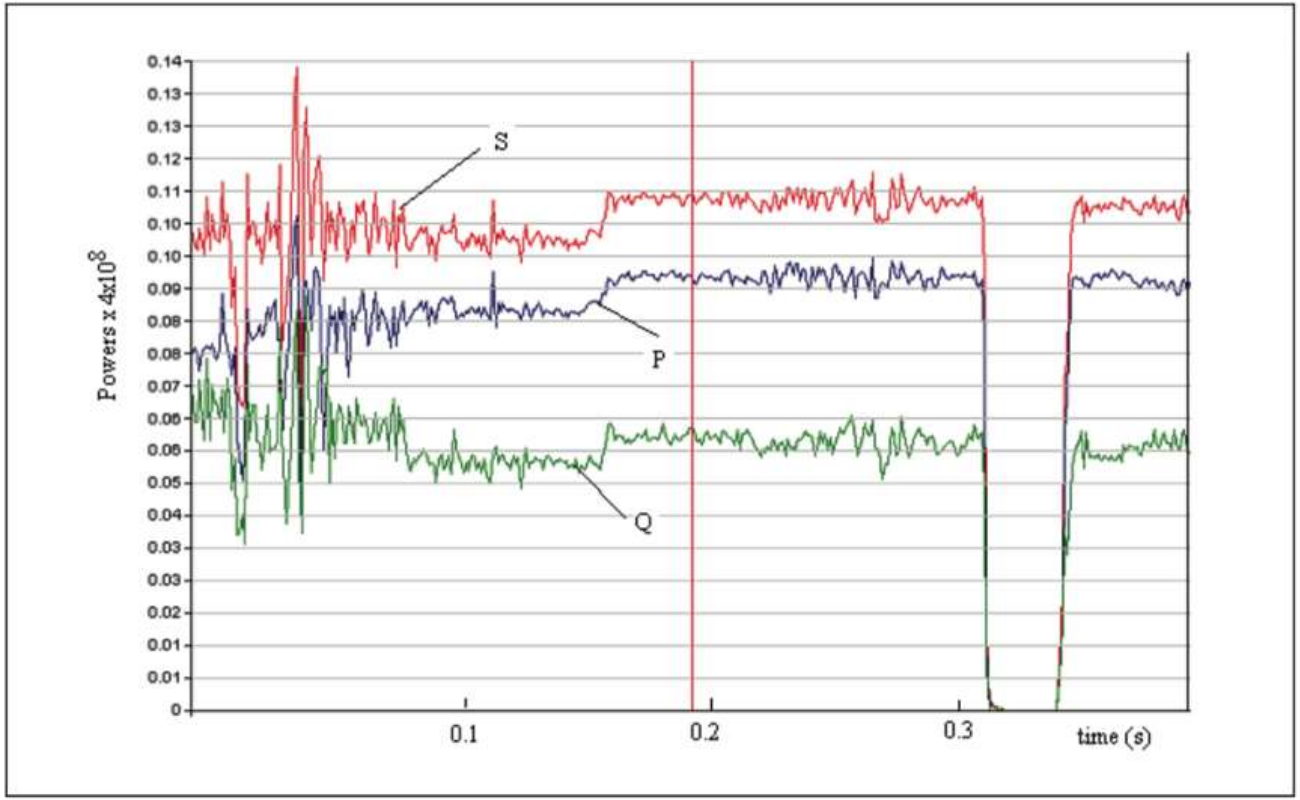



Fig. 12. The real measurements of powers (P, Q, S) for a technological cycle of arc furnace

Source: http://cdn.intechopen.com/pdfs/14961.pdf

# Voltage Flicker

- Flicker is a power quality issue that is predominately associated with noticeable changes in light output from incandescent lighting caused by minor changes in voltage levels.
- Flicker can exist in fluorescent lighting but requires somewhat larger voltage deviations
- Flicker is rarely harmful for equipment
- Studies have shown that sensitivity depends on how much the illumination changes (magnitude), how often it occurs (frequency), and the type of work activity undertaken
- Typical frequency range is from 0.5 Hz to 30.0 Hz, with observable magnitudes starting at less than 1%. The most sensitive frequency range for voltage flicker is approximately 5 Hz to 10 Hz

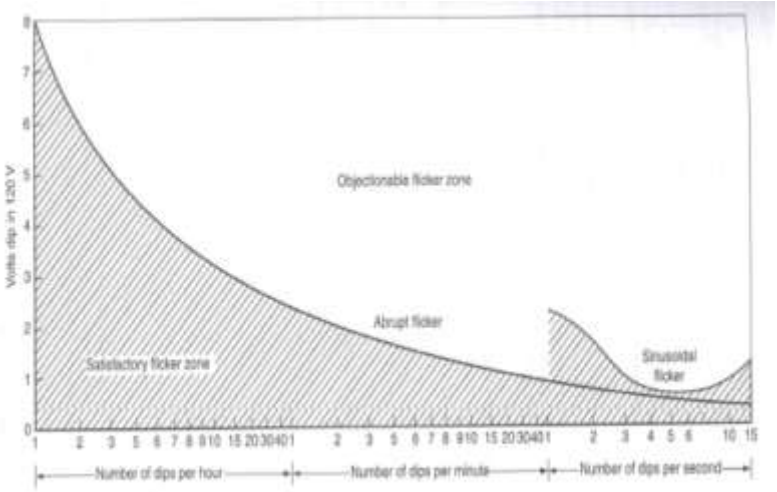
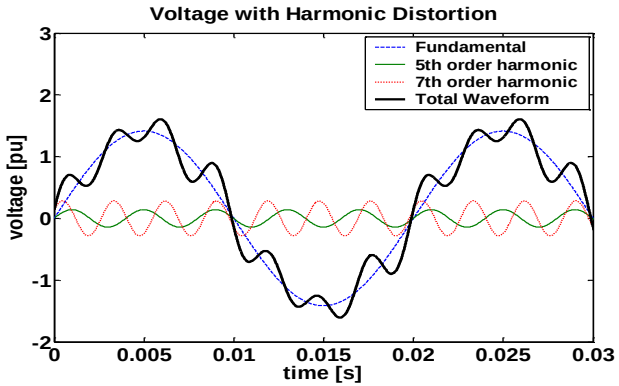


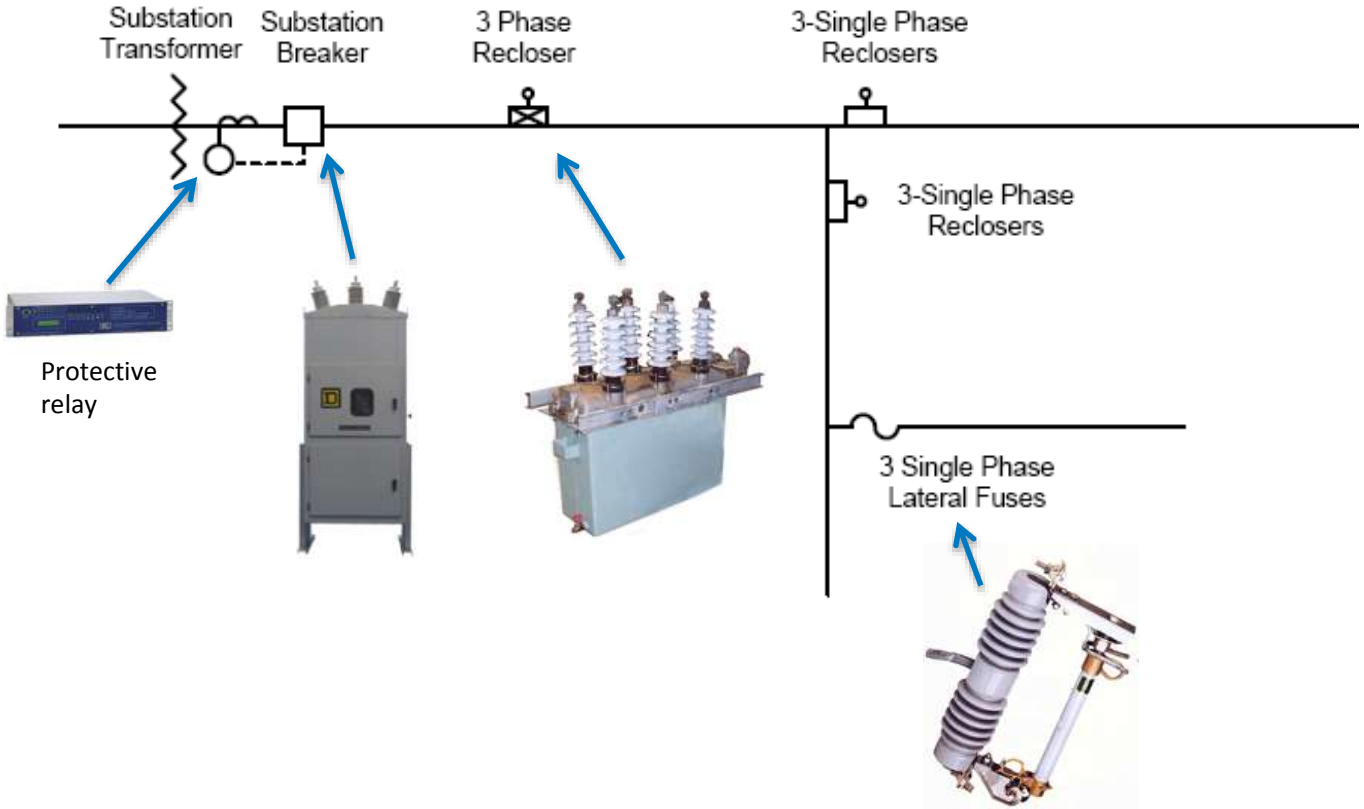

FIGURE 9.21 Permissible voltage-flicker-limit curve.

# Harmonics

- The voltage distortion created by nonlinear loads may create voltage distortion beyond the premise's wiring system, through the utility, to another user.
- Harmonic currents can cause transformers to overheat, in turn overheating neutral conductors.
- This overheating may cause erroneous tripping of circuit breakers and other equipment malfunctions.



# Protection Systems



# NREL Grid Connection/ HPC information

- Relatively level 5MW average demand for entire site on a 15MW+ non-dedicated distribution feeder
- HPC/DC uses 1,150 KW and 850,000 KWH/month
- Single utility feed at 13.2kV with back up feeder and backup generators
- General communicate with utility on an as needed basis, no specific communications with utility for HPC operations
- No known events from HPC
- NREL is on a primary general rate with TOC pricing
- Xcel has a “ratchet clause” based on the $3.86/KW Distribution portion of demand charges. The only time it has come into consideration is operating the NWTC 5 MW dyno.

# Summary

- Will adding a 10MW-40MW cause a power issue?
  - It depends on service rating. Service from grid needs to be properly sized from substation to loads to minimize voltage variations and stay within current ratings.

- Does the speed of turning on/off a large load cause a power system issue?
  - Yes – the ramp rate can cause system issues with protection systems and flicker

- Does the type of load affect the grid?
  - Yes – Loads with high harmonics can cause grid issues

NREL Power Systems Engineering Center
https://www.nrel.gov/grid/

# NREL … Providing Solutions to Grid Integration Challenges

## Thank You!

www.nrel.gov

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# PANEL SESSION

## BEN, TORSTEN, GRANT, ANNA MARIA, JIM, STEVE

- Thank you for your participation!
- Please help us with feedback for next year

- https://www.surveymonkey.com/r/Y9F3MCN