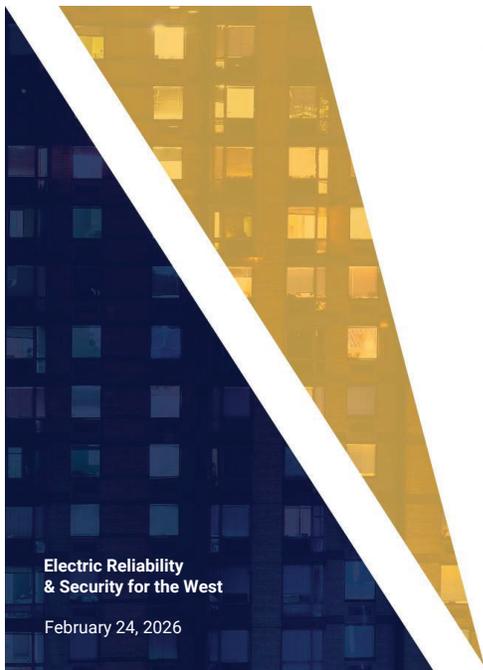


<Limited-Disclosure>



# Course Materials



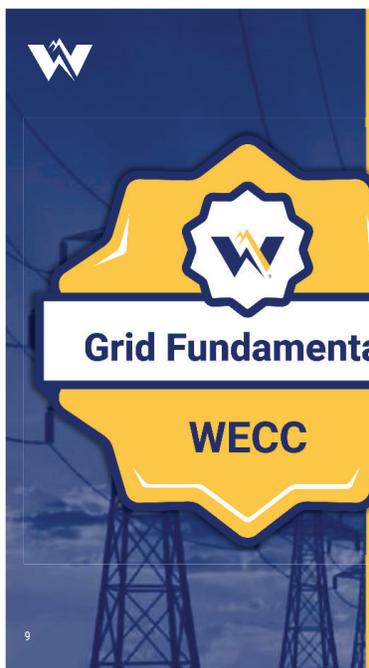


Electric Reliability  
& Security for the West

February 24, 2026



Day 1



9

## Section 1 – References (Refer to Abbreviations/ Definitions/Information)

Donovan Crane  
*Senior Engineer*



10

## Section 2 – Electricity Basics

Donovan Crane  
*Senior Engineer*

***“Just imagine, for a minute, life without energy.***

*You don’t have a way to run a laptop, mobile phone, TV, or video games. You don’t have lights, heat, air conditioning, or even the Internet to read this letter.*

*About 1.3 billion people — 18 percent of the world’s population — don’t need to imagine. That’s what life is like for them every day.”*

— Bill Gates

11

## Importance of Electricity

***“Electricity is what keeps our society tethered to modern times.***

*Taking down [the] grid would scatter millions of Americans in a desperate search for light, [we would] tumble back into something approximating the mid-nineteenth century.”*

—Ted Koppel

12

## Quick Snapshot of Time | 585 BCE–1895

**Origins of the word  
“Electricity”**



Greek Roots  
Elektron/Amber

**Complete  
AC System**



Jarunga Hydroelectric Plant  
Sibernik, Croatia

~2,500 Years Later

13

### Birth of an Electric Utility



Commonwealth Edison Company  
(Now Exelon)

118 Years Later

### Too Many Advancements to List



Utilities, Regulations, New Generation,  
New Storage, Large Interconnections....

14

## Characteristics of Electricity

**(V) Voltage**

**(I) Current**

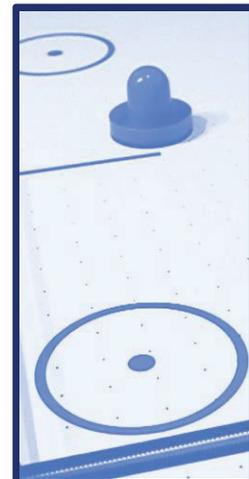
**(R) Resistance**



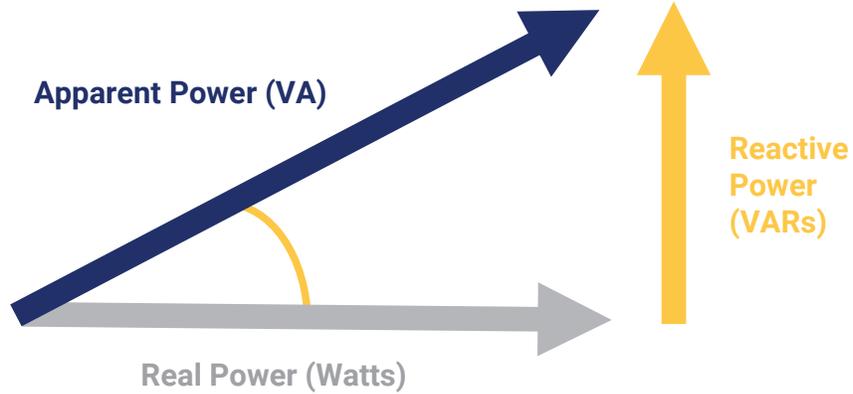
15

## Real vs. Imaginary

- **Real Power**
  - Does the work; it does the heating, lighting, and turning of motors, etc.
  - Real Power is measured in: **Watts (W)**
- **Reactive Power**
  - Supports magnetic & electric fields required for AC systems to function
  - Reactive Power is measured in: **Volt-Amperes-Reactive (VAR)**
- **Formula for Apparent Power (Volt-Amp or VA)**
  - **Watts** (Real Power) And **VARs** (Reactive Power)
  - Results in **VAs** (Apparent Power)



16

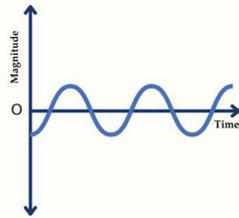


## Nikola Tesla

### Alternating Current (AC)



Nikola Tesla



Current flows back and forth.



Car Motors



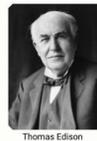
Appliances



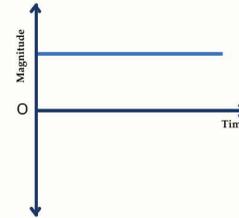
Radio Signals

## Thomas Edison

### Direct Current (DC)



Thomas Edison



Current only flows in one direction.



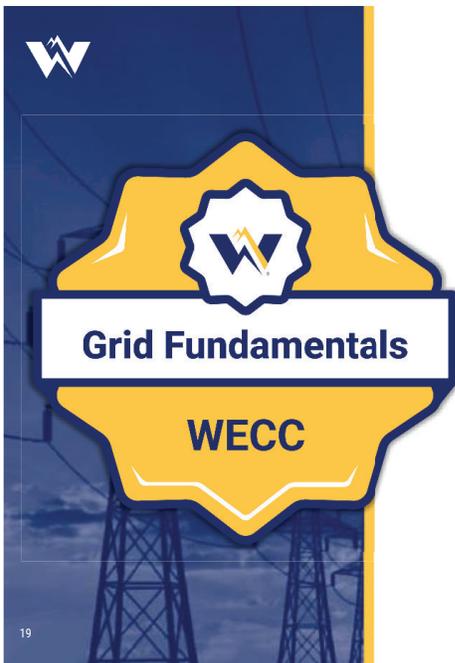
Solar Panels



Batteries

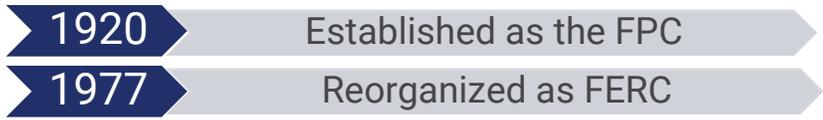


Charging Devices



# Section 3 — Regulation: Who, How, and Why

**Mark Willis**  
*Principal Risk Engineer*  
**Donovan Crane**  
*Senior Engineer*



### FERC's Mission

Reliable, efficient, and sustainable energy for customers

- Independent agency
- Regulates high-voltage interstate transmission of electricity and natural gas transportation



The **Government Authority** is the agency responsible for the governance of the electric system in their state, province, or country. Examples would be FERC, BCUC, State Public Service Commissions, etc.

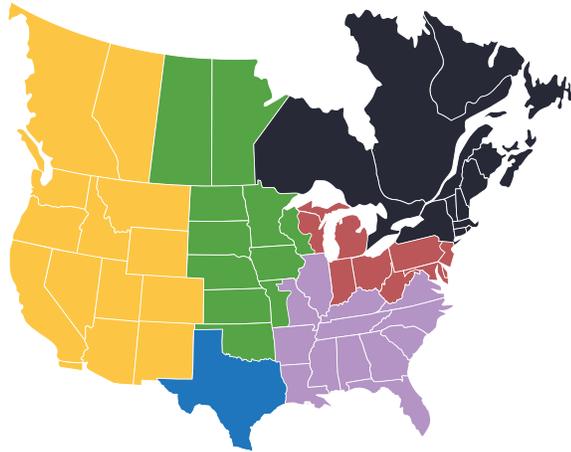
**NERC is the Electric Reliability Organization (ERO)** responsible for establishing and enforcing reliability standards for the BPS. NERC is subject to oversight from both FERC and Canadian governmental authorities.

The ERO Enterprise has six **Regional Entities** responsible for the unique needs of their regional constituents while ensuring that all parts of the interconnected electric system are reliably operated. WECC is a Regional Entity.

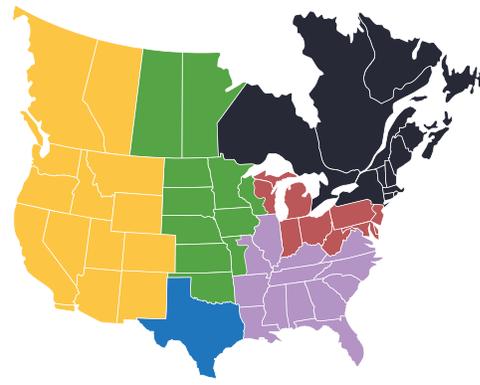
**Registered Entities** are those required by law to register with NERC and comply with NERC Reliability Standards.



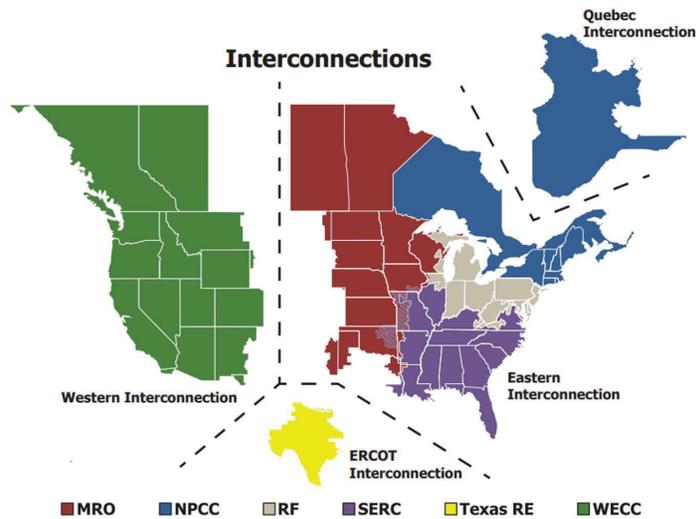
**NERC**  
NORTH AMERICAN ELECTRIC  
RELIABILITY CORPORATION



## Four Interconnections – Six Regional Entities – One ERO



## Four Interconnections – Six Regional Reliability Entities





**WECC'S MISSION**

---

*"To effectively and efficiently mitigate risks to the reliability and security of the Western Interconnection's Bulk Power System."*

26



**WECC'S VISION**

---

*"A Reliable and Secure Bulk Power System in the Western Interconnection."*

27

***"Responsibility to design, build, operate, and maintain the largest person-made machine in the world."***

---

28

## Largest of six Regional Entities

Designated as the Regional Entity for the Western Interconnection

Has responsibility to help create, monitor, enforce reliability standards and promote activity that ensures reliability and security

### Service Territory

- **Canada** (Alberta and British Columbia)
- Northern part of **Baja California, Mexico**
- All or parts of the **14 Western states**



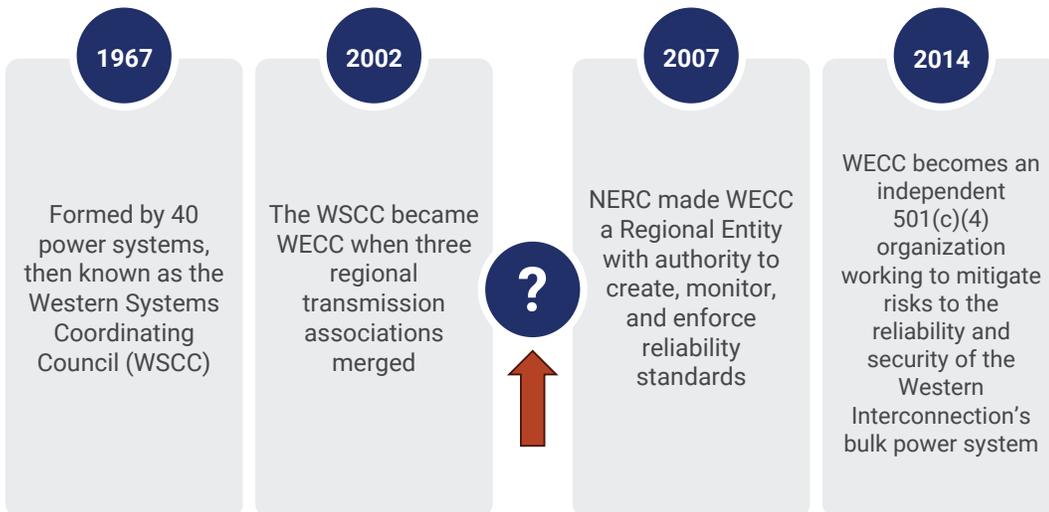
## Our Stakeholders



## How We Create Value | Independence, Perspective, and Partnership

- WECC is a 501(c)(4) social welfare, non-profit corporation that exists to ensure a reliable Bulk Power System in the Western Interconnection
- WECC is funded by Load-Serving Entity (LSE) assessments authorized by FERC under Section 215 of the Federal Power Act
- WECC is governed by a nine-member Board of Directors and the CEO





32

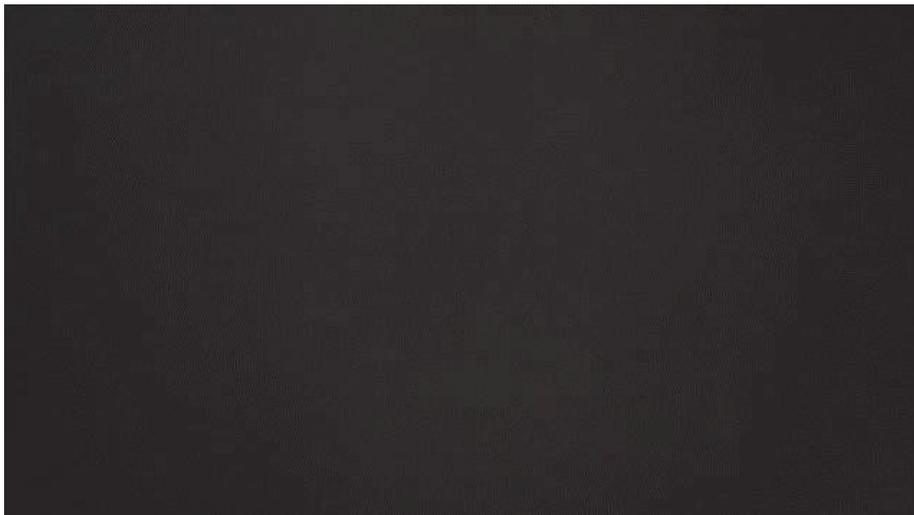
## The Line

***“There’s a thin line between civilization and chaos, and that line is electricity.”***

—Charles Haden Savage

33

## 2003 – The Great Northeast Blackout



34

## Disturbances – The change from Voluntary to Mandatory

- Before the current mandatory compliance with reliability standards, entities voluntarily adhered to "good utility practice."
- However, following three significant interconnection disturbances, voluntary adherence was no longer sufficient.



35

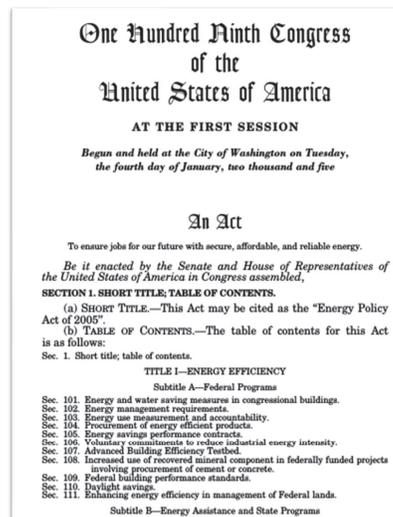
## 2003 – The Great Northeast Blackout



36

## Energy Policy Act of 2005

- Federal Power Act, Section 215 calls for mandatory enforceable standards
- FERC certifies an Electric Reliability Organization – the ERO (NERC)
- NERC may delegate authority to Regional Entities; e.g., WECC
- Industry develops standards, approved by FERC



37

## TITLE XII—ELECTRICITY

### SEC. 1201. SHORT TITLE.

This title may be cited as the "Electricity Modernization Act of 2005".

### Subtitle A—Reliability Standards

#### SEC. 1211. ELECTRIC RELIABILITY STANDARDS.

(a) IN GENERAL.—Part II of the Federal Power Act (16 U.S.C. 824 et seq.) is amended by adding at the end the following:

#### \*SEC. 215. ELECTRIC RELIABILITY.

16 USC 824a.

"(a) DEFINITIONS.—For purposes of this section:

"(1) The term 'bulk-power system' means—  
 "(A) facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof); and

"(B) electric energy from generation facilities needed to maintain transmission system reliability.  
 The term does not include facilities used in the local distribution of electric energy.

"(2) The terms 'Electric Reliability Organization' and 'ERO' mean the organization certified by the Commission under subsection (c) the purpose of which is to establish and enforce reliability standards for the bulk-power system, subject to Commission review.

"(3) The term 'reliability standard' means a requirement, approved by the Commission under this section, to provide for reliable operation of the bulk-power system. The term includes requirements for the operation of existing bulk-power system facilities, including cybersecurity protection, and the design of planned additions or modifications to such facilities to the extent necessary to provide for reliable operation of the bulk-power system, but the term does not include any requirement to enlarge such facilities or to construct new transmission capacity or generation capacity.

"(4) The term 'reliable operation' means operating the elements of the bulk-power system within equipment and electric system thermal, voltage, and stability limits so that instability, uncontrolled separation, or cascading failures of such system will not occur as a result of a sudden disturbance, including a cybersecurity incident, or unanticipated failure of system elements.

Electricity  
Modernization  
Act of 2005.  
42 USC 15801  
title.

- Title XXII – Electricity
- Subtitle A – Reliability Standards
- ~ 5 pages of the 550-page Act

## NERC Registered Entities

	Entities that Must Register	Entities that Need to be Certified
Reliability Coordinator (RC)	✓	✓
Transmission Operator (TOP)	✓	✓
Balancing Authority (BA)	✓	✓
Planning Authority/Planning Coordinator (PA/PC)	✓	
Transmission Planner (TP)	✓	
Transmission Service Provider (TSP)	✓	
Transmission Owner (TO)	✓	
Resource Planner (RP)	✓	
Distribution Provider (DP)	✓	
Generator Owner (GO)	✓	
Generator Operator (GOP)	✓	
Reserve Sharing Group (RSG)	✓	
Frequency Response Sharing Group (FRSG)	✓	
Regulation Reserve Sharing Group	✓	

## NERC Entity Functions

### Electric utility tasks...

- Generate, transmit power, plan, coordinate

### Scenario:

A company wants to build a new generator. They become a Generator Owner (GO).

They need a ...



- Balancing Authorities (BA)
- Distribution Providers (DP)
- Generator Operators (GOP)
- Generator Owners (GO)
- Planning Coordinator (PC)
- Transmission Operators (TOP)
- Transmission Owners (TO)
- Transmission Planner (TP)
- Transmission Service Provider (TSP)
- etc.

**FAC-003-4 Transmission Vegetation Management**

**A. Introduction**

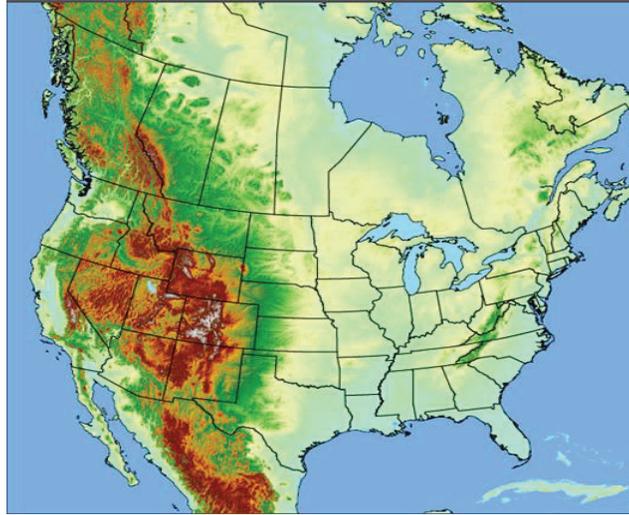
- Title:** Transmission Vegetation Management
- Number:** FAC-003-4
- Purpose:** To maintain a reliable electric transmission system by using a defense-in-depth strategy to manage vegetation located on transmission rights of way (ROW) and minimize encroachments from vegetation located adjacent to the ROW, thus preventing the risk of those vegetation-related outages that could lead to Cascading.
- Applicability:**
  - Functional Entities:**
    - Applicable Transmission Owners**
      - Transmission Owners that own Transmission Facilities defined in 4.2.
    - Applicable Generator Owners**
      - Generator Owners that own generation Facilities defined in 4.3.
  - Transmission Facilities:** Defined below (referred to as "applicable lines"), including but not limited to those that cross lands owned by federal<sup>1</sup>, state, provincial, public, private, or tribal entities:
    - Each overhead transmission line operated at 200kV or higher.
    - Each overhead transmission line operated below 200kV identified as an element of an IROL under NERC Standard FAC-014 by the Planning Coordinator.
    - Each overhead transmission line operated below 200 kV identified as an element of a Major WECC Transfer Path in the Bulk Electric System by WECC.

## NERC Mandatory Standards Subject to Enforcement

Acronym	Title	# of Standards
BAL	Resource and Demand Balancing	9
CIP	Critical Infrastructure Protection	12
COM	Communications	2
EOP	Emergency Preparedness and Operations	6
FAC	Facilities Design, Connection, and Maintenance	9
INT	Interchange Reliability Operations and Coordination	4
IRO	Interconnection Reliability Operations and Coordination	13
MOD	Modeling, Data, and Analysis	14
NUC	Nuclear	2
PER	Personnel Performance, Training, and Qualifications	3
PRC	Protection and Control	23
TOP	Transmission Operations	6
TPL	Transmission Planning	2
VAR	Voltage and Reactive	3

## Standards Development

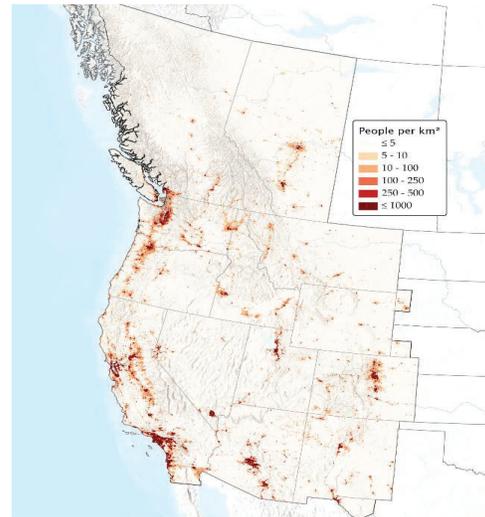




44

## Population Centers

Due to the unique geography, demography, and history, the Western Interconnection is distinct in many ways from the other North American interconnections

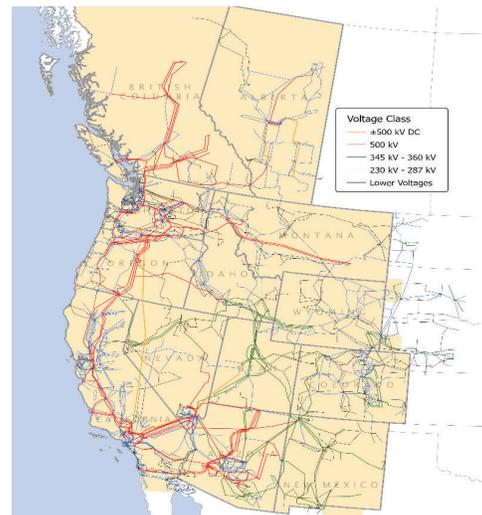


45

## Transmission Lines

The Western Interconnection is made up of about 136,000 miles of transmission lines

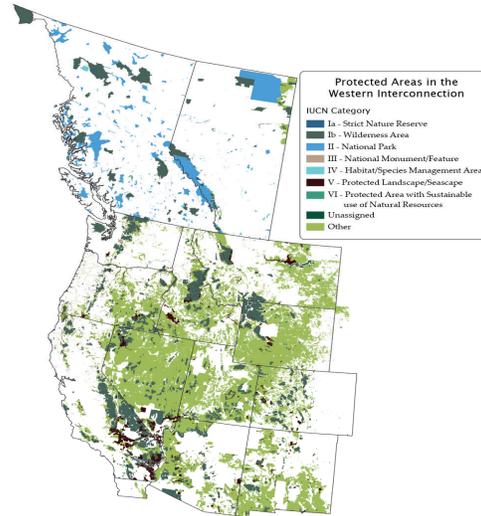
Long, high-voltage lines were built to connect remote generating resources with distant population centers, primarily along the West Coast



46

## Nearly 87% of the Western Interconnection is public or protected land

Compare that to just 27% in the combined Eastern, Texas, and Quebec interconnections



# WECC-Approved Regional Standards

- BAL-004-WECC Automatic Time Error Correction
- FAC-010 System Operating Limits Methodology for the Planning Horizon (with Regional Difference)
- FAC-011 System Operating Limits Methodology for the Operations Horizon (with Regional Difference)
- FAC-501-WECC Transmission Maintenance
- IRO-006-WECC Qualified Transfer Path Unscheduled Flow Relief
- VAR-001 Voltage and Reactive Control (with Regional Variance)
- VAR-501-WECC Power System Stabilizer (PSS)

# WECC



## Reliability Planning and Performance Analysis



50

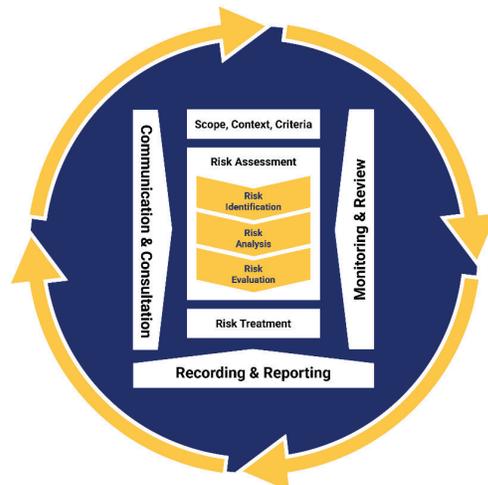
## Reliability Modeling and Assessments

- Model Development – Achieved Through Stakeholder Partnerships
  - WECC is the MOD-032 ERO Designee for Building Interconnection-wide Cases
  - WECC develops several types of models for stakeholder and WECC use including power flow cases, dynamic models, the Anchor Dataset and more!
- Reliability Assessments – support ERO assessments and perform own assessments like the Western Assessment of Resource Adequacy

51

## Reliability Risk Management and Data Services

- Provides a structured framework to identify, prioritize, and treat risks
- Stakeholder involvement is critical
- Always evolving
- Providing data services both internally and externally



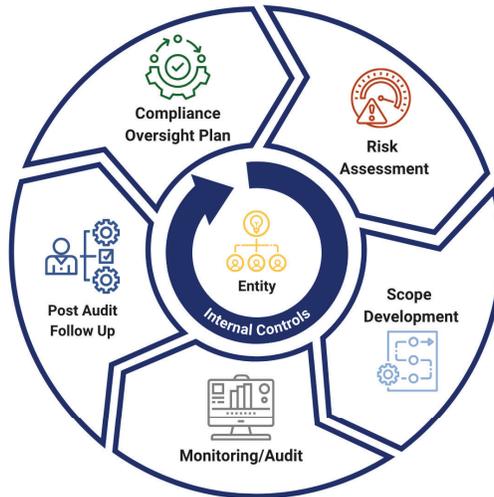
Learn More:  
[WECC's Risk Management Program](#)  
[NERC's Risk Framework](#)

52

# Reliability and Security Oversight <Limited Disclosure>

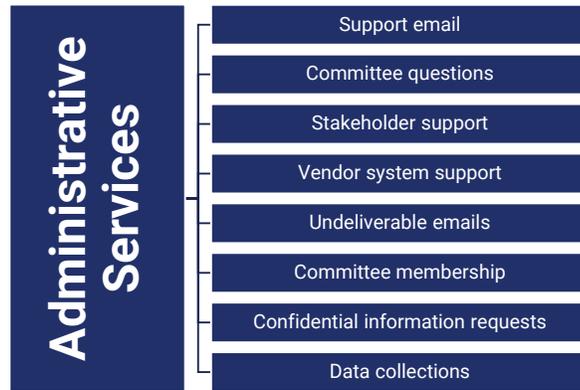


# Reliability & Security Oversight

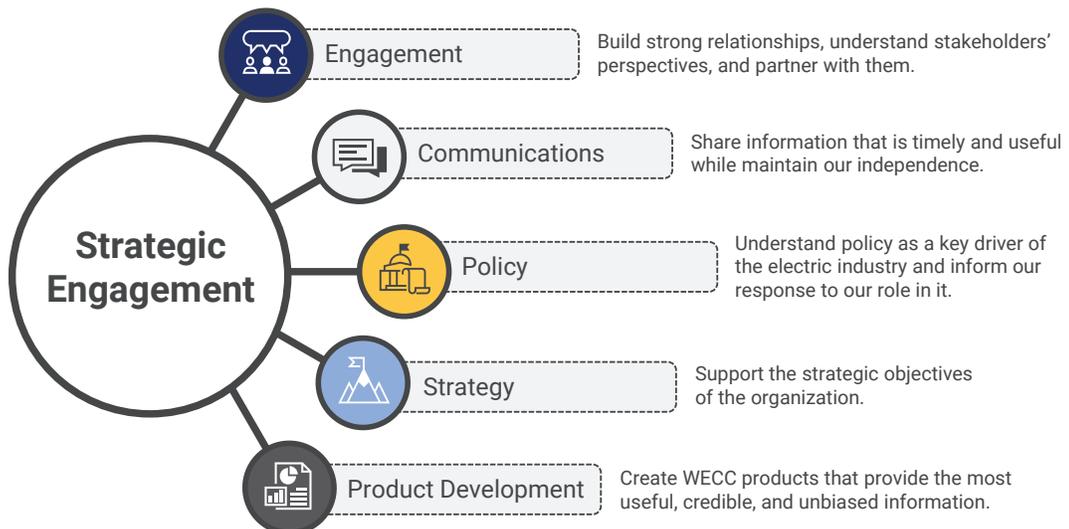


# Administrative Services





For help with any of the following topics, please contact the service desk:  
[support@wecc.org](mailto:support@wecc.org)





<Limited-Disclosure>



# Section 4 – The Electric Grid

**Donovan Crane**  
*Senior Engineer*

**Mark Willis**  
*Principal Risk Engineer*

66



## The Largest Machine Ever Built



67



## Interconnected Power Systems



68

- Generation
- Transmission
- Distribution



Generation Station

# The Electrical System Structure

- Generation
- Transmission
- Distribution



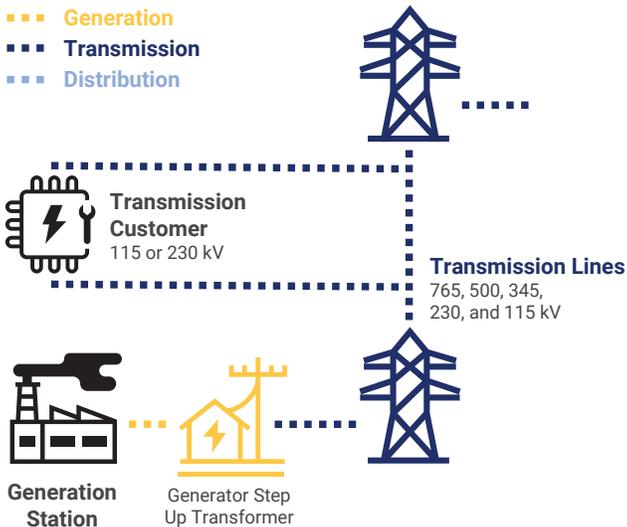
Generation Station

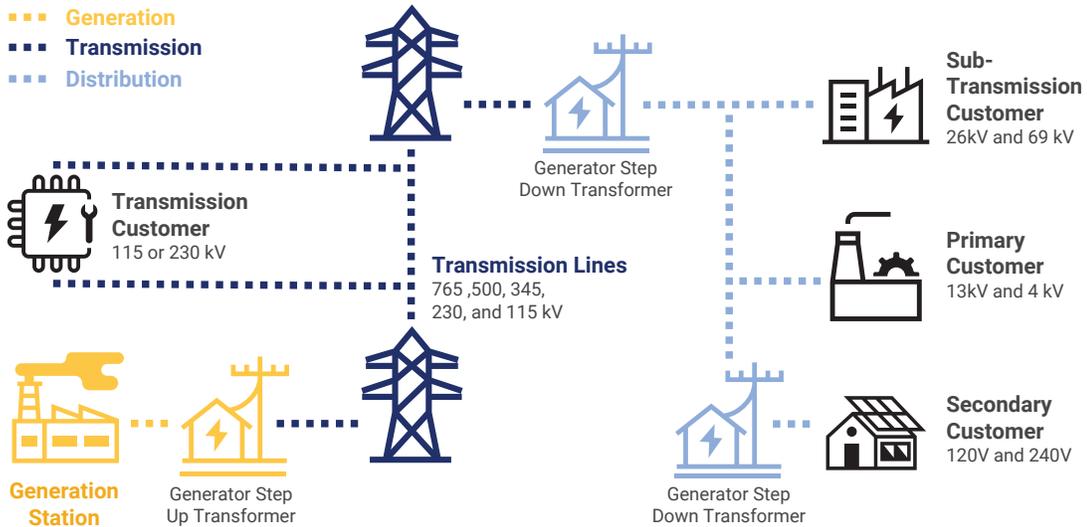


Generator Step Up Transformer

# The Electrical System Structure

- Generation
- Transmission
- Distribution





## Section 4.1 – Generators

**Mark Willis**  
*Principle Risk Engineer*  
**Donovan Crane**  
*Senior Engineer*

73

### What is Electricity?

**Electricity is the flow of electrons in a circuit**

Electricity is created in three main ways:

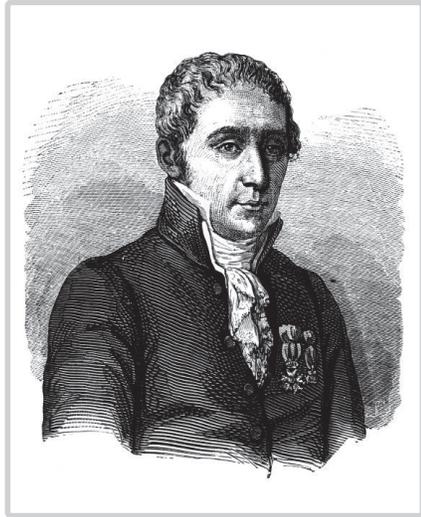
1. Electromagnetic conversion (e.g., steam, hydro, wind)
2. Chemical reaction (e.g., battery, fuel cell)
3. Solid state conversion (e.g., solar panel)



74

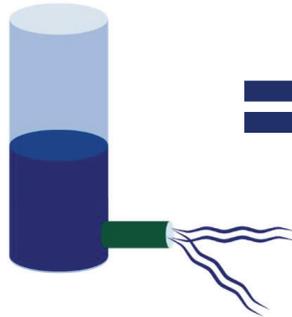
Named after:  
**Alessandro Volta**

Time Period: **1745–1827**      Unit of measurement: **Volts (V)**

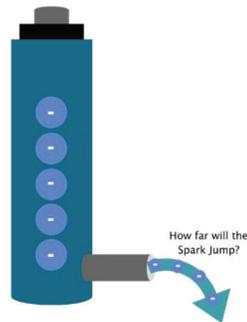


What is it?  
**A measure of electrical pressure**  
• **How far will the spark jump?**

Water pressure



Electricity



**1.5V–9V**  
Batteries



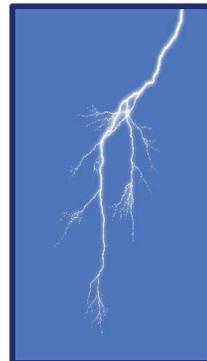
**12V**  
Car Battery



**120V**  
House

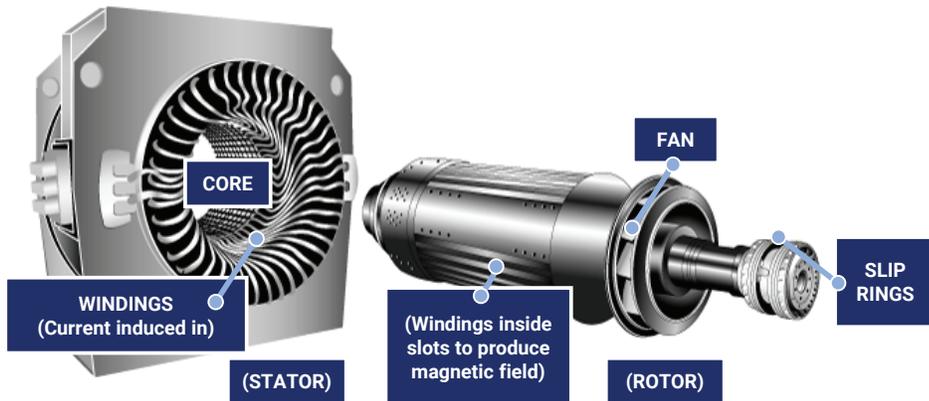


**47kV–500kV**  
Transmission

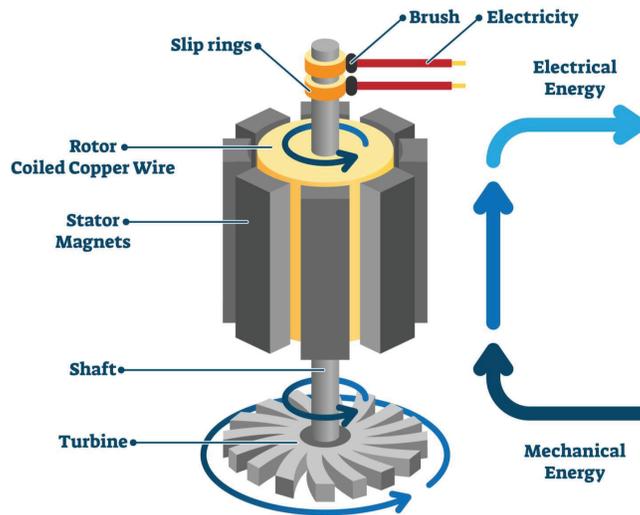


**1,000,000+ V**  
Lightning

A machine in which mechanical energy is changed to electrical energy



A machine in which mechanical energy is changed to electrical energy

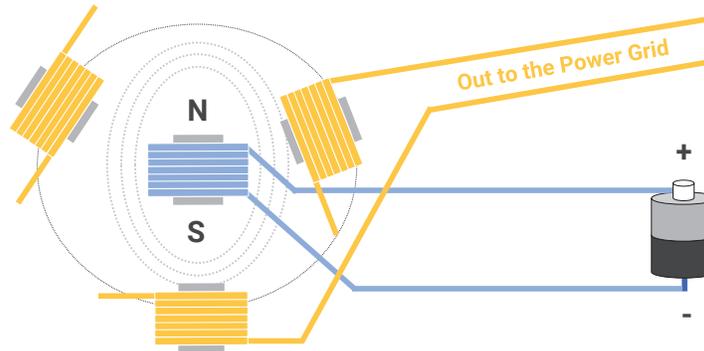




81

## Excitation System

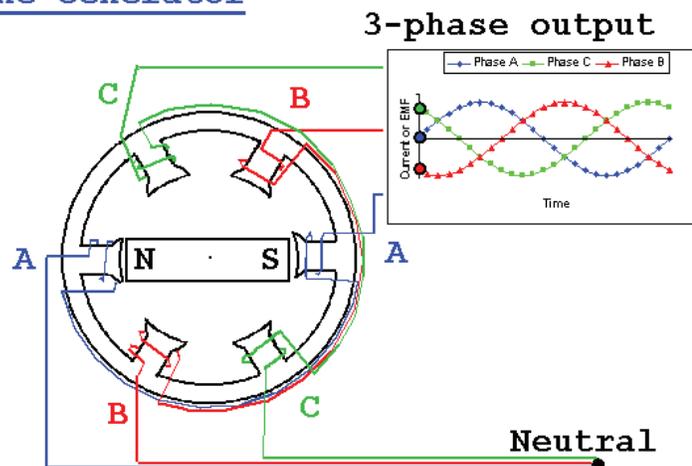
- Supplies direct current to the rotor
- Turns the rotor into a magnet
- Can vary current to affect generator voltage and VAR output



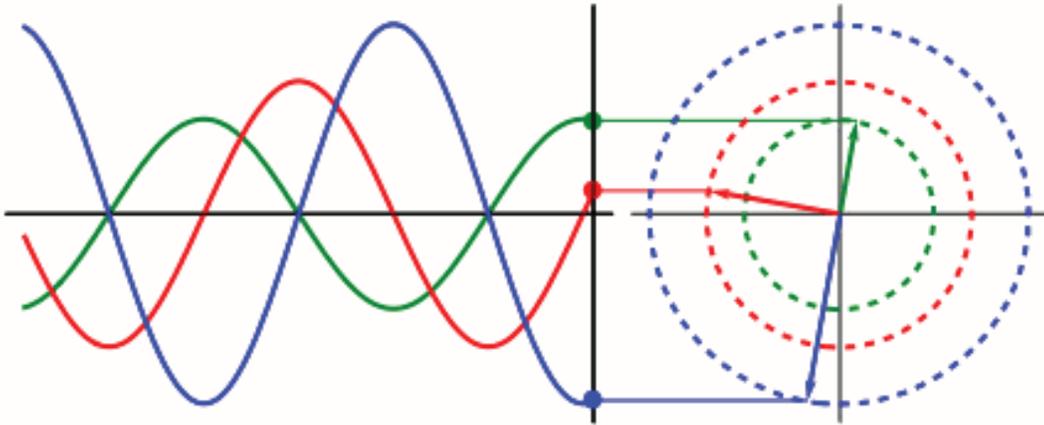
82

## Generating 3-Phase Power

### The Generator

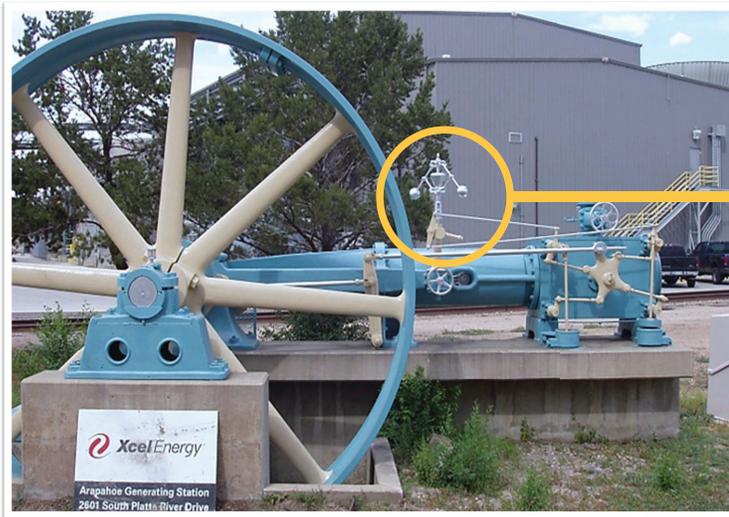


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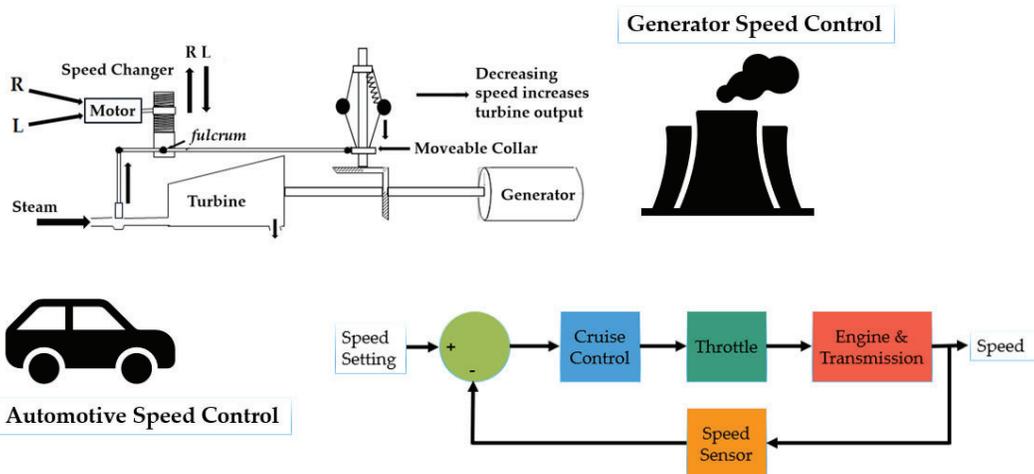
84

### Turbine Governor Controls



85

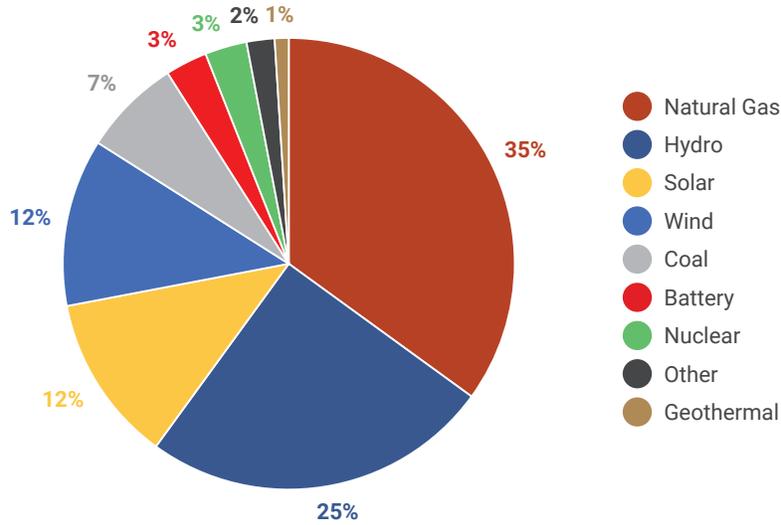
### Governor – Speed Control



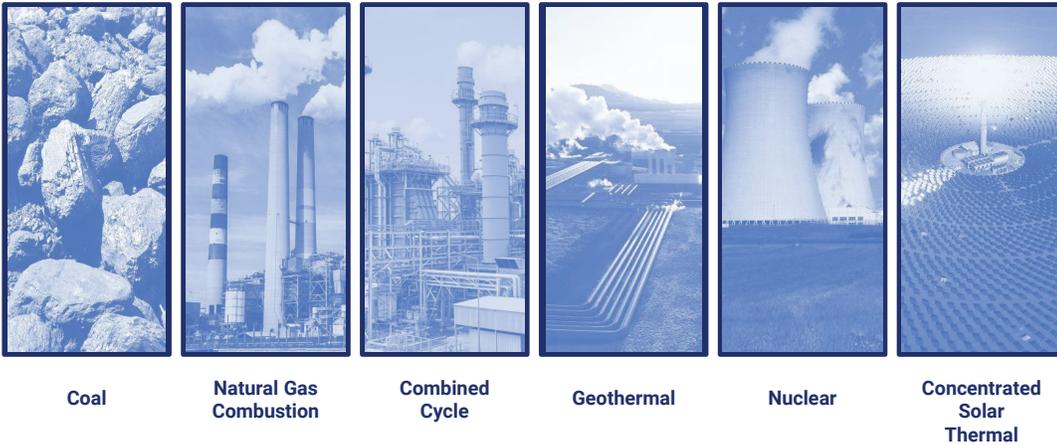
86

## 2024 Total Installed Capacity (299.5 GW) – by generation type

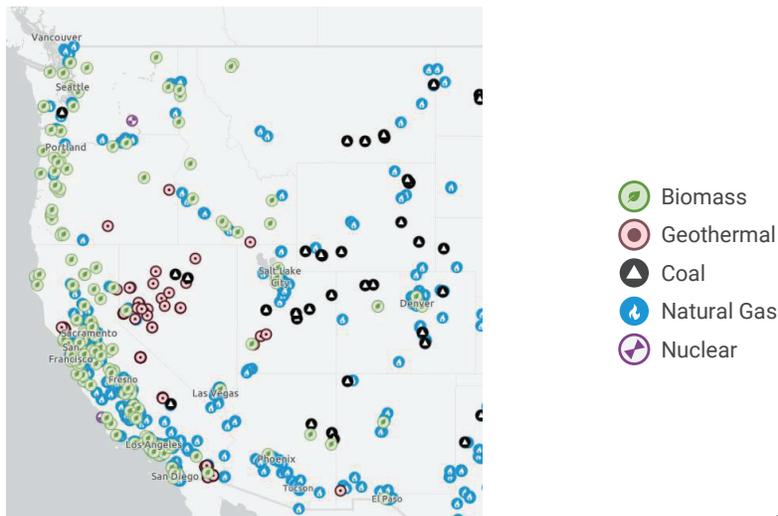
<Limited Disclosure>

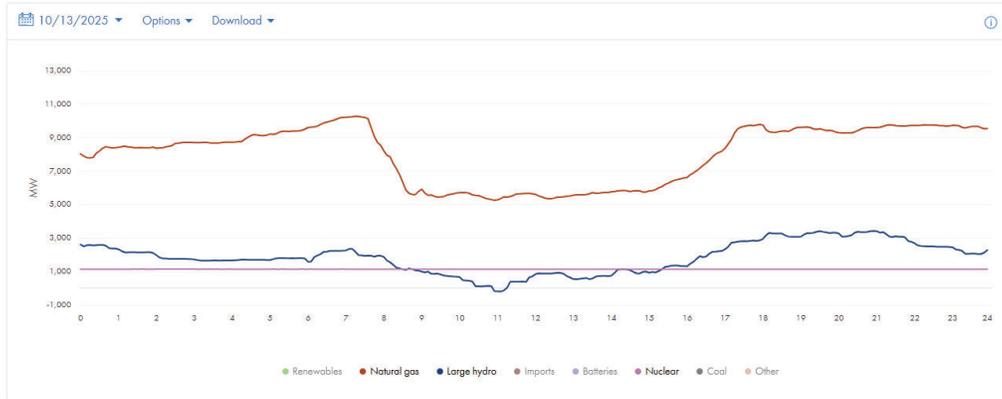


## Thermal Fuel Sources



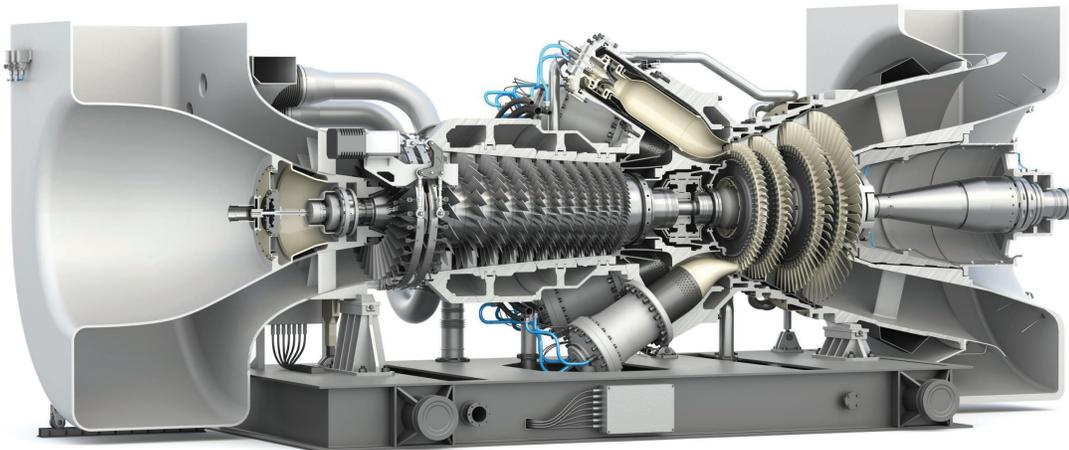
## Thermal Generation





90

## Combustion Turbine

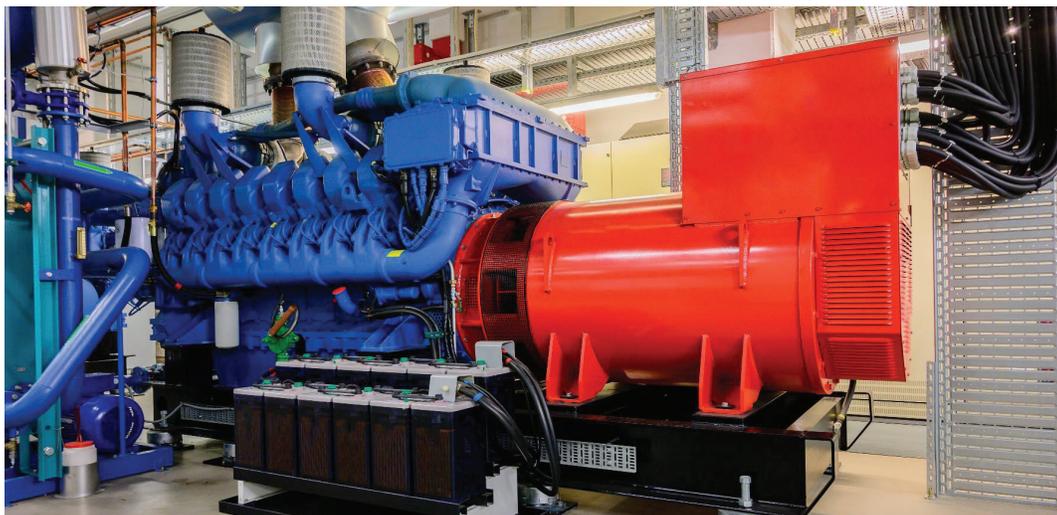
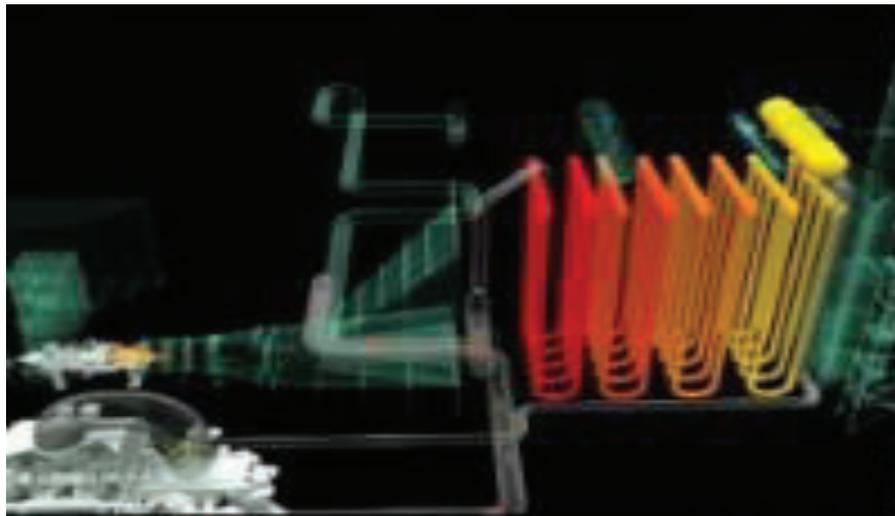
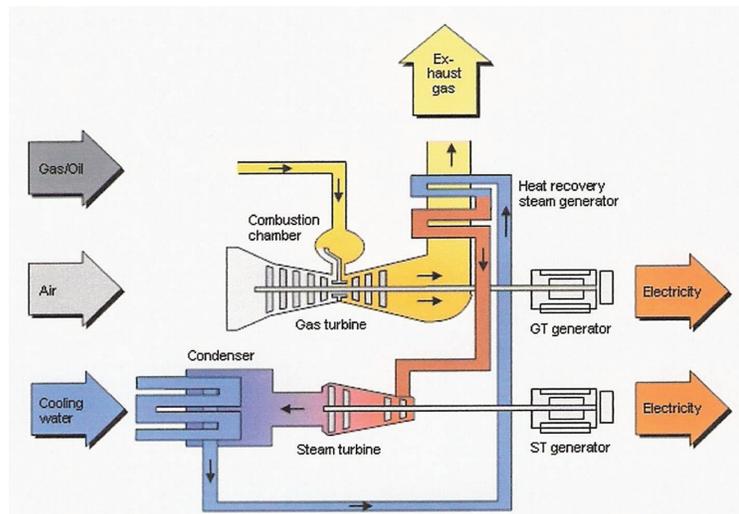


91

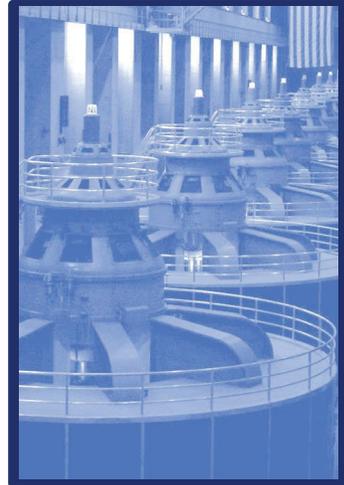
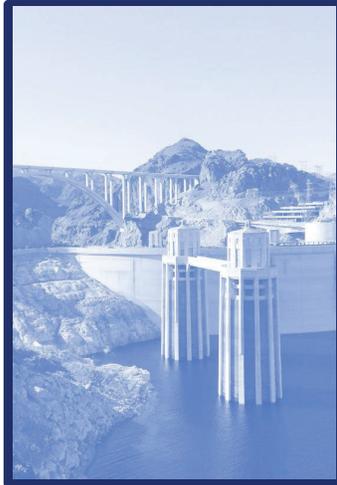
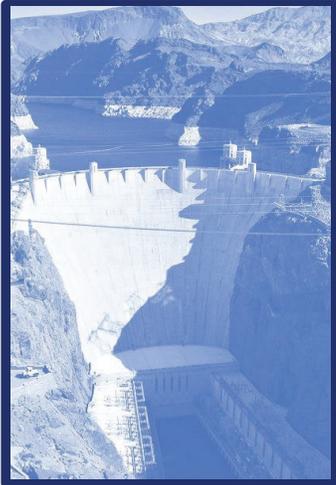
## Combined Cycle



92

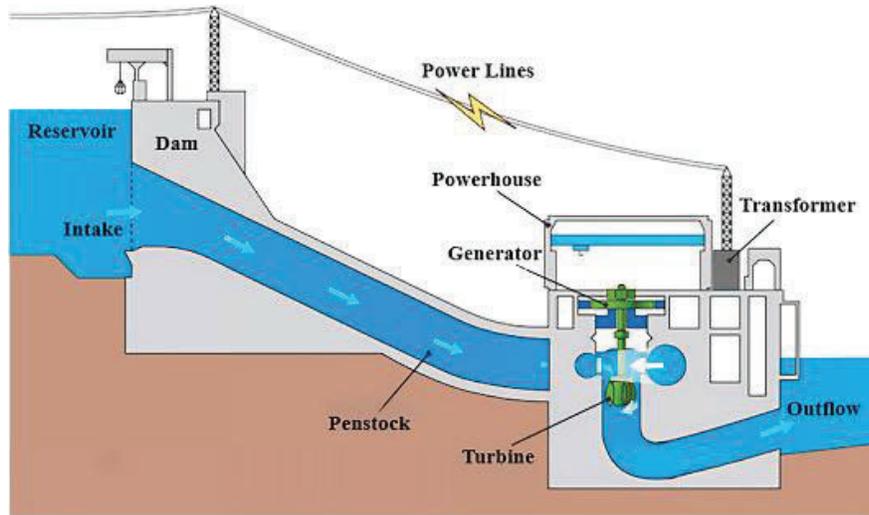


## Hydroelectric – Hoover Dam 2,080 MW



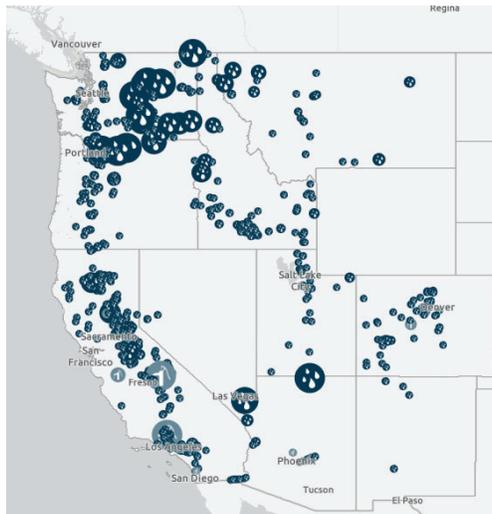
96

## Hydroelectric Power Generation



97

## Hydroelectric Generation



98

Courtesy of eia.gov



## Wind Generation

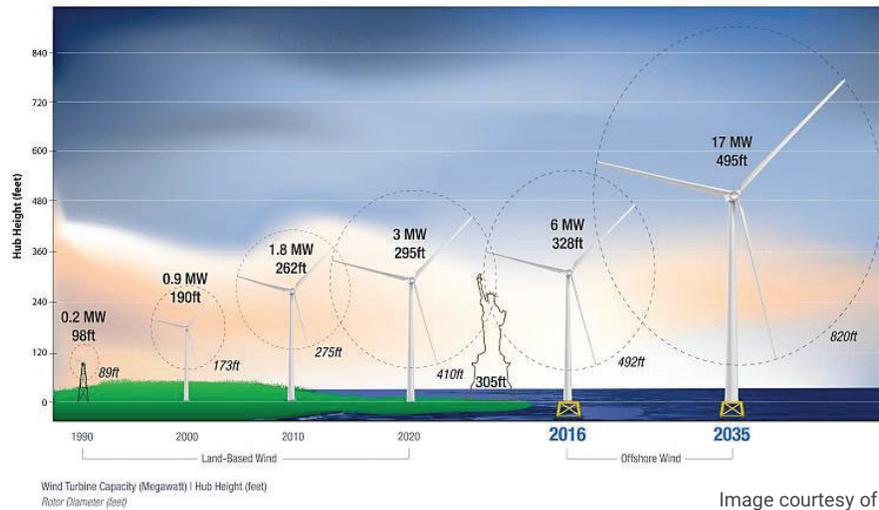
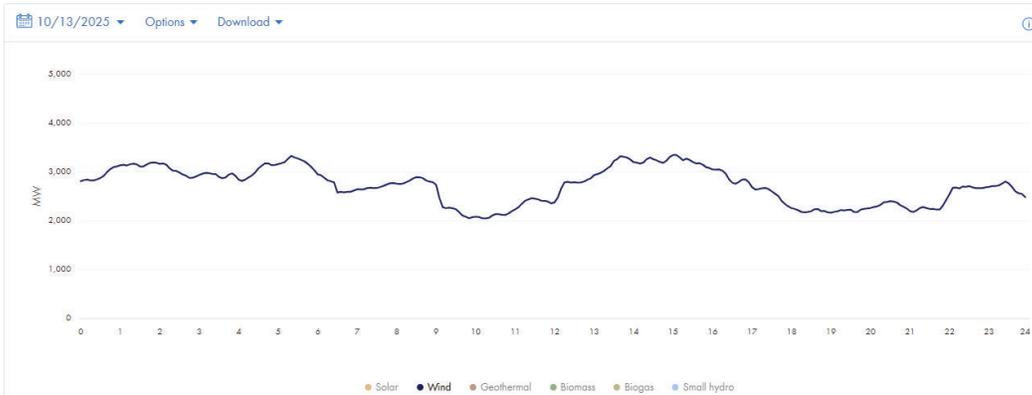


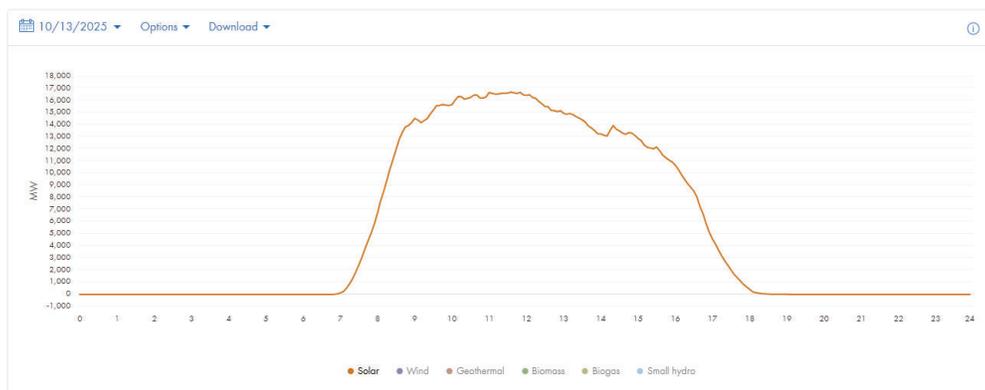
Image courtesy of Energy.gov

## Variable Energy Resource





Courtesy of eia.gov





105



106



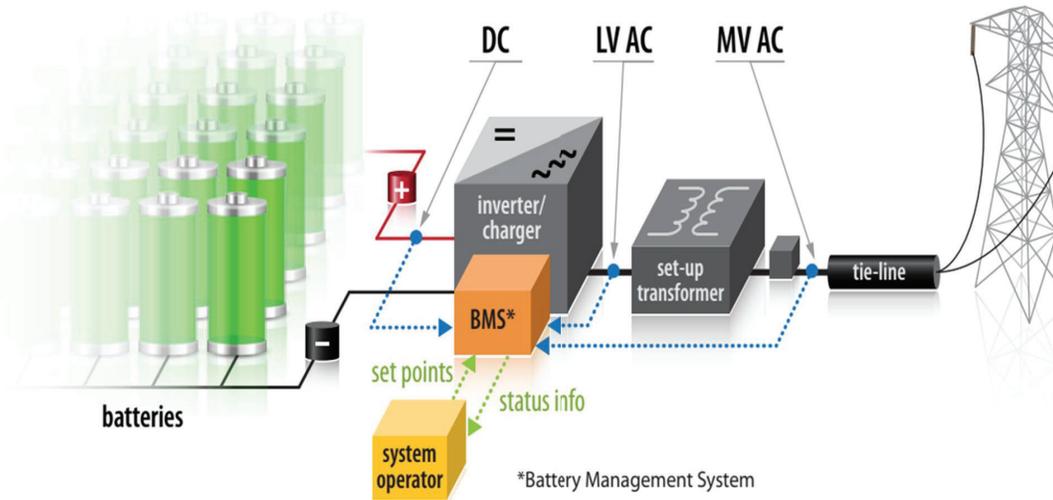
107

Courtesy of eia.gov



The Federal Energy Regulatory Commission's (FERC) regulations define an electric storage resource as *"a resource capable of receiving electric energy from the grid and storing it for later injection of electric energy back to the grid."*

## Battery Energy Storage System (BESS)



Key components of BESS interconnected at the transmission substation level. LV AC represents a low-voltage AC connection, while MV AC represents a medium-voltage AC connection. *Source: Denholm (2019)*

## LITHIUM-ION BATTERY

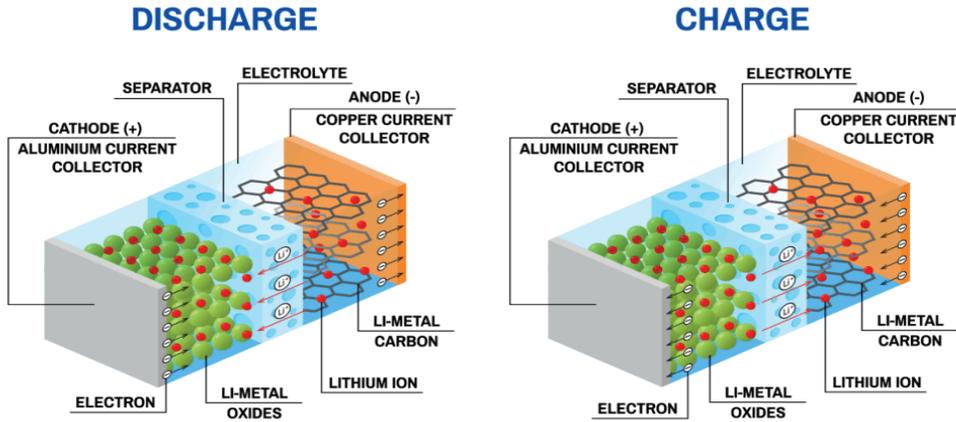
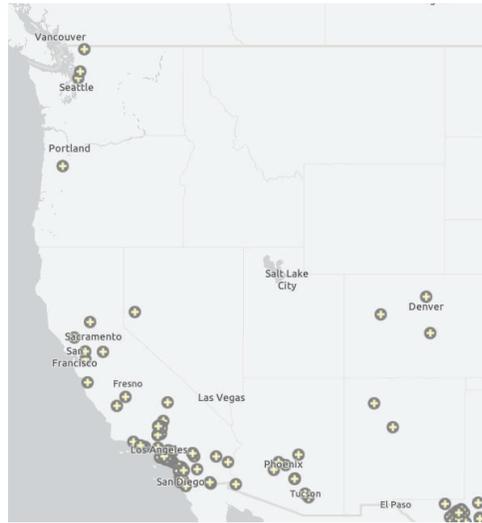


Image courtesy of Go Energy Link

111

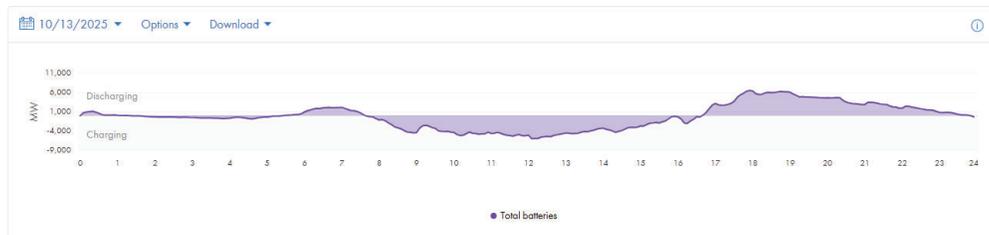
## Battery Storage



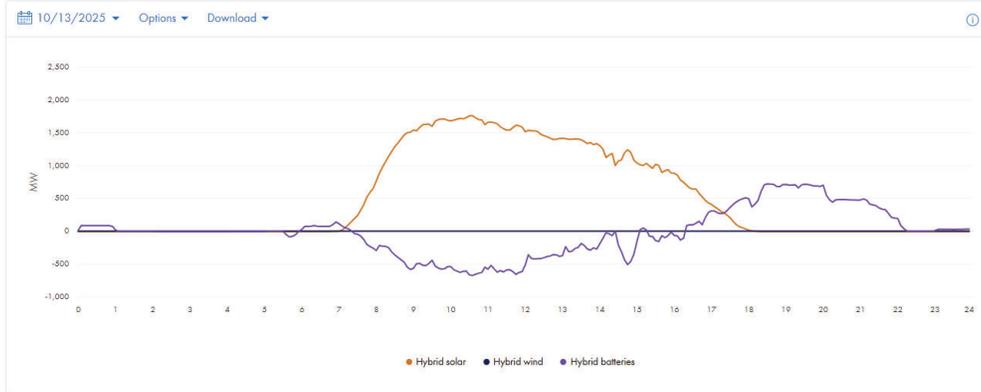
Courtesy of eia.gov

112

## Battery Storage



113

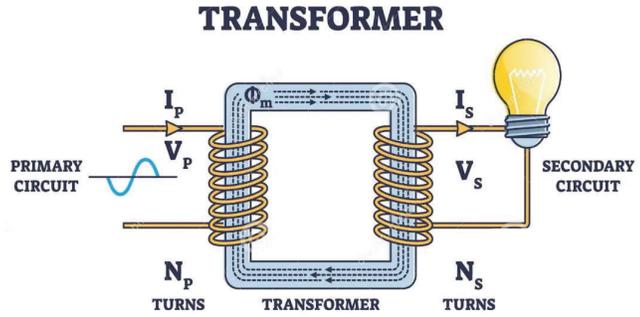


## Battery for a House



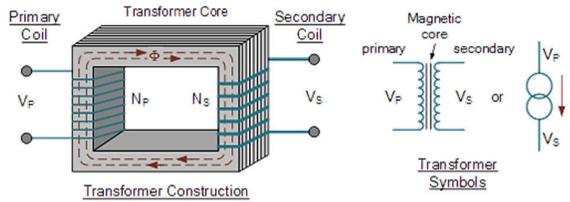
# Section 4.2 – Transformers & Substations

Donovan Crane  
Senior Engineer

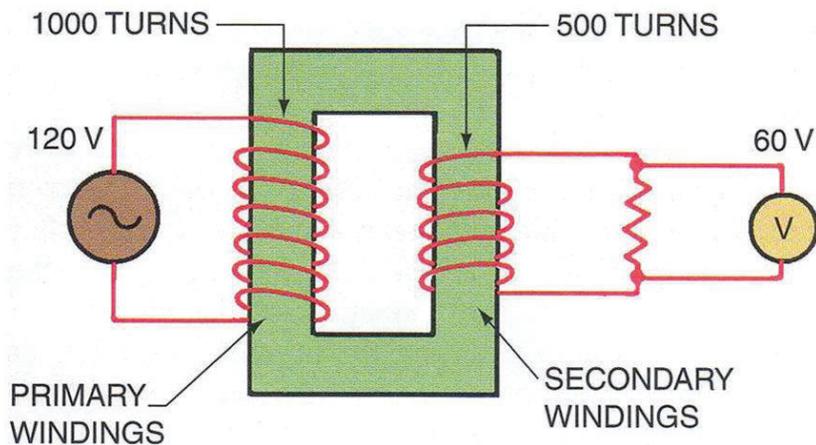


124

- 1 Changes from high voltage to low voltage
- 2 Enables high-voltage transmission of power
- 3 Works only with AC power



125



126



127

## Distribution Transformers

### Distribution Transformer

Reduces voltage to a level usable by customers

#### Transformers Sit On:

- Poles
- concrete pads
- underground vaults



128

## Substation Transformer



129



130

## Transformer Cooling

Oil to air (OA)

ONAN (Oil – Natural Circulation, Air – Natural Circulation)

Forced air (FA)

ONAF (Oil – Natural Circulation, Air – Forced Circulation)

Forced-oil and air (FOA)

OFAF (Oil – Forced Circulation, Air – Forced Circulation)

131

## The Electrical System Structure

- ■ ■ Generation
- ■ ■ Transmission
- ■ ■ Distribution



Generation Station



Generator Step Up Transformer



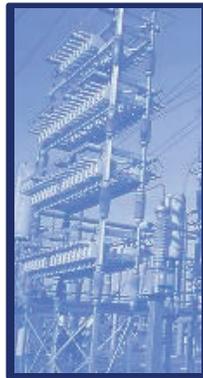
132



## Equipment Functions



**Voltage:**  
Transformers  
Step-up,  
Step-down



**Voltage Control:**  
Capacitors,  
Reactors,  
Transformers



**Interruption & Isolation:**  
Circuit Breakers,  
Disconnects

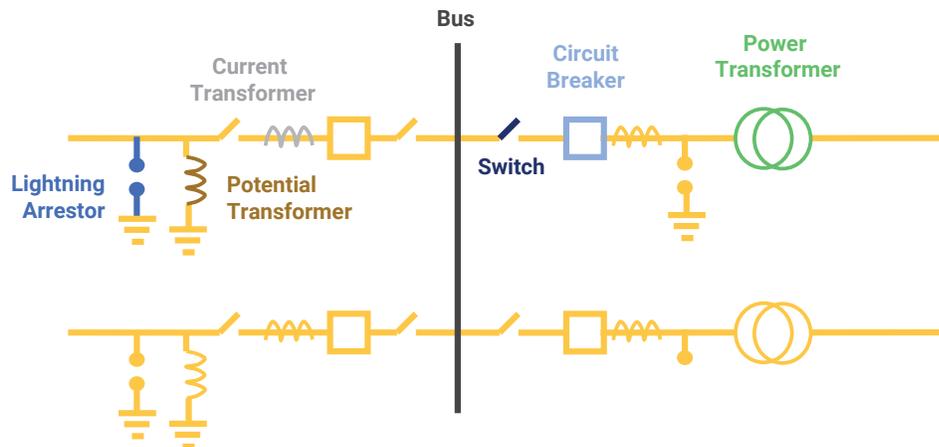


**Protection:**  
Protective  
Relays



**Metering & Telemetry:**  
Instrument Transformers,  
Meters, Telemetry  
equipment

## Substations





Oil Circuit Breaker



Air Circuit Breaker



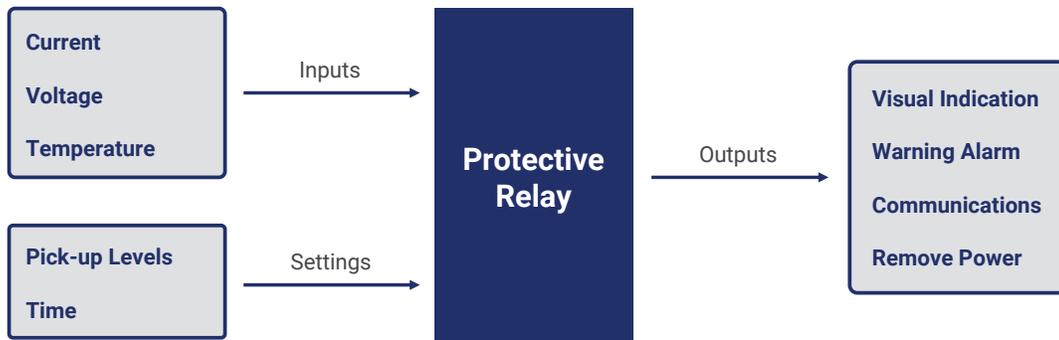
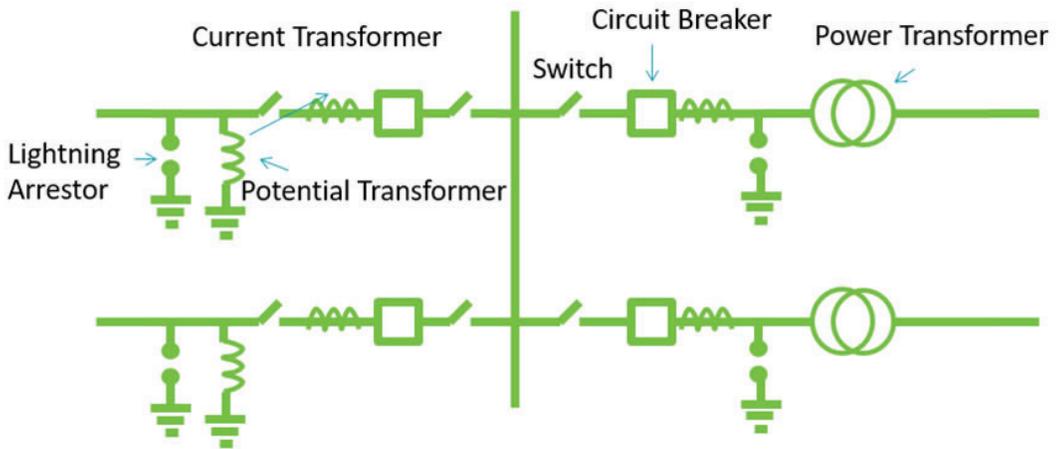
SF6 Circuit Breaker

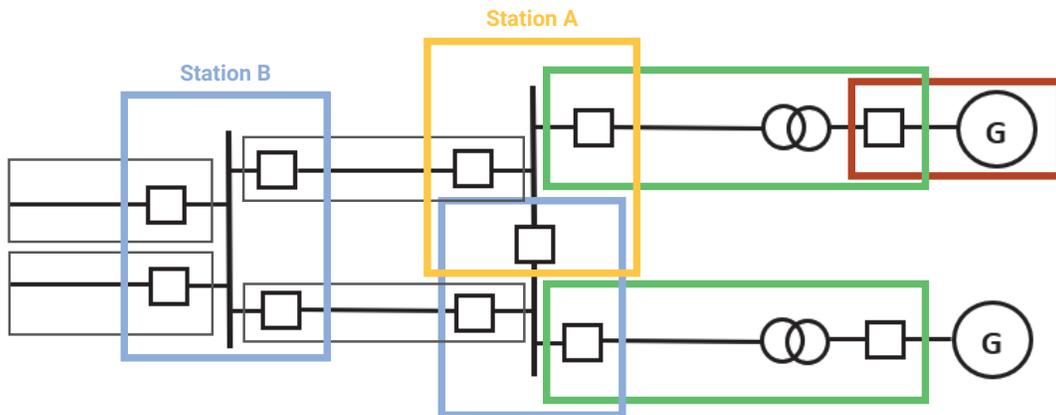


Switchgear controls allow for monitoring and control of equipment within the switchyard



Relays monitor the electrical characteristics of the power system and act for abnormal conditions





## Section 4.3 – Transmission & Distribution

Donovan Crane  
Senior Engineer

Named after:  
**André-Marie Ampère**



Time Period: **1775–1836**      Unit of measurement:  
**Ampere (Amp, A, I)**  
**'I' is used in formulas**



What is it?  
**Movement of charge through a conductor**

- **Electrons carry the charge**
- **Think “gallons per second”**

## What Does Current Do?



Move Electrons



Melts Things



Required for High Power Devices



Heat Things Up



Creates Magnetic Fields

## Current



**.2–.5mA**  
Sensation



**60W = .54Amps**  
Lightbulb



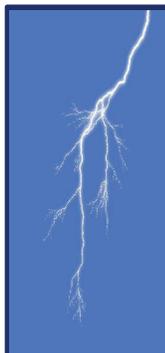
**1–2Amps**  
Phone  
Charger



**~10Amps**  
Toaster



**~1,000Amps**  
Transmission  
Tower



**20,000+ Amps**  
Lightning

Named after:  
**Georg Ohm**

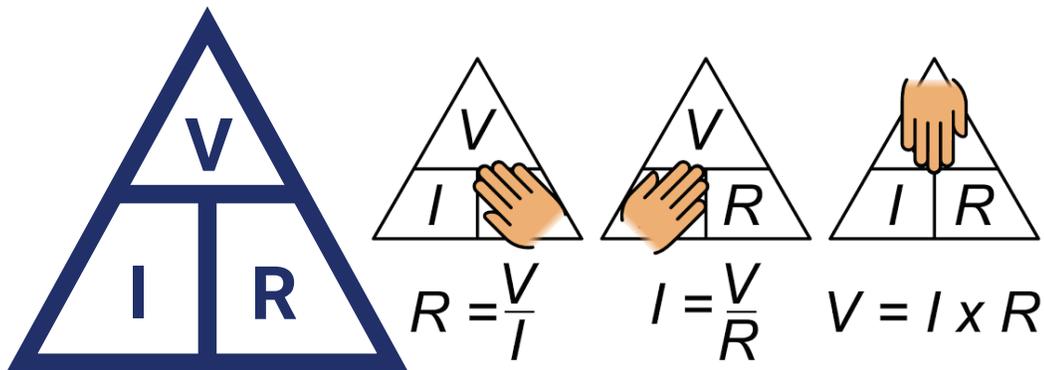
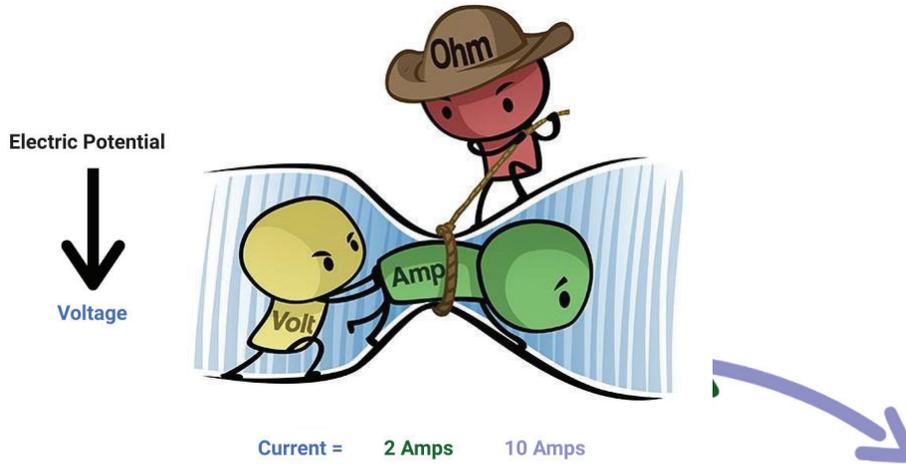
Time Period: **1789–1854**      Unit of measurement: **Ohms ( $\Omega$ )**



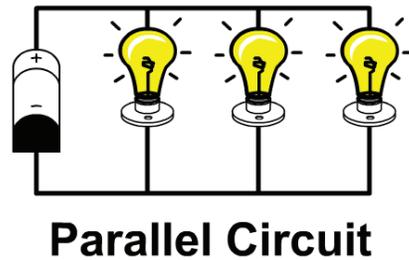
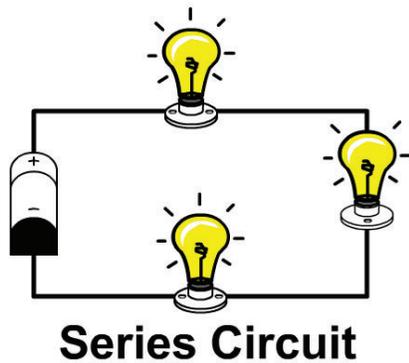
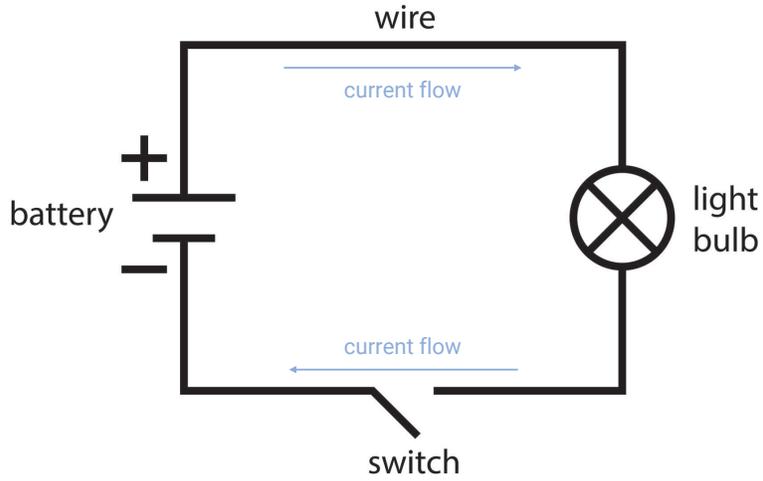
What is it?

**Opposes current**

- **Converts electric energy into heat**
- **A Resistor provides resistance to the circuit**



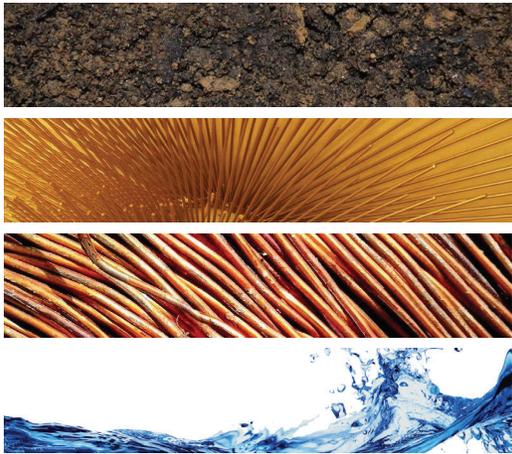
They are all tied together!



## Insulators



## Conductors



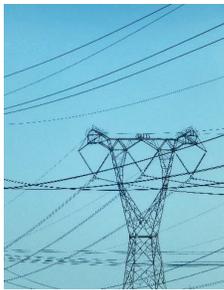
## Conductors

Conductors carry the electricity  
Big current requires big conductors

### Underground



### Above Ground



## Conductors – Types



**ACSR**

Aluminum cable steel reinforced



**AAAC**

All aluminum-alloy cable



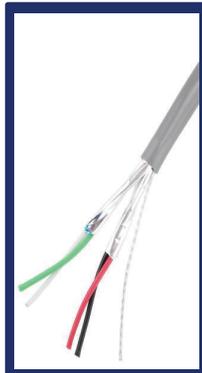
**CU**

Copper



**OPGW**

Optical ground wire (shield wire)



**EHS**

Extra high strength steel (shield wire)

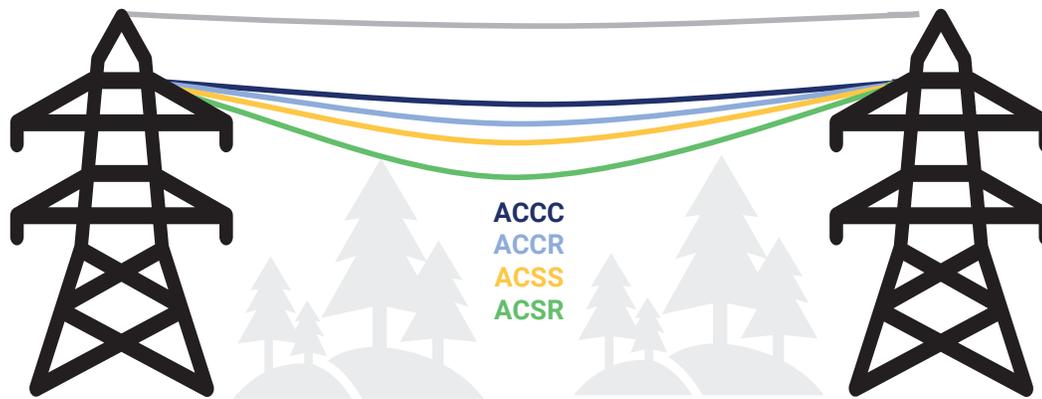
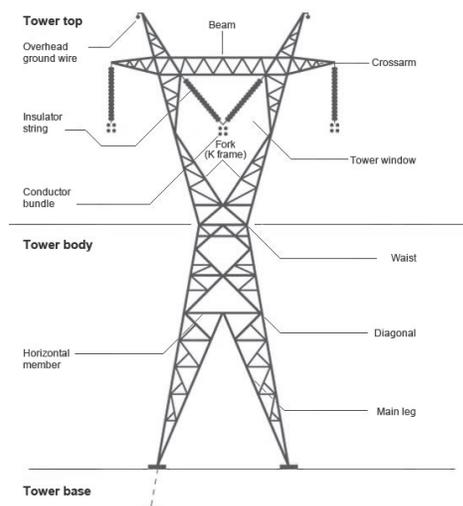


Figure 1: Sag Comparison at 180 C



1. Conductors
2. Towers
3. Insulators
4. Shield wires
5. Rights-of-way



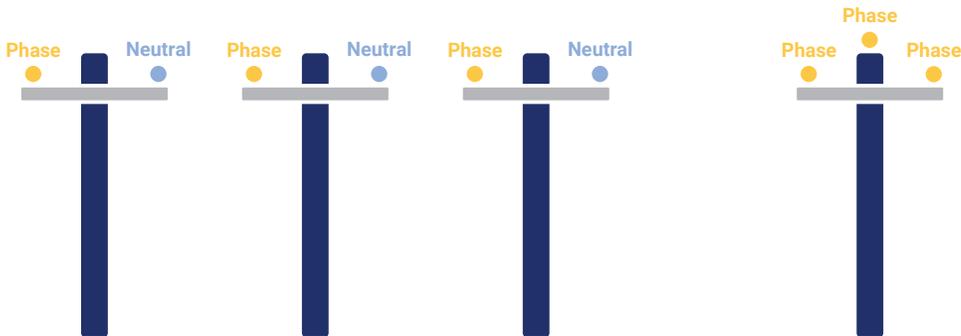


160

## Three-Phase Circuits

3 – Single Phase Lines  
6 Conductors

1 – Three Phase Line  
3 Conductors



161

## Electrical Characteristics of Line

Resistance → Losses

Inductance → Voltage Drop

Capacitance → Voltage Rise

162

### Real Power

Does the work; it does the heating, lighting, and turning of motors, etc.

- Real Power is measured in:  
**Watts (W)**

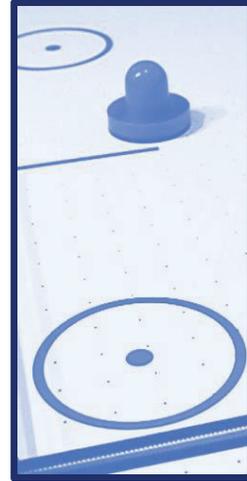
### Reactive Power

Supports magnetic & electric fields required for AC systems to function

- Reactive Power is measured in:  
**Volt-Amperes-Reactive (VAR)**

### Formula for Apparent Power (Volt-Amps or VA)

**Watts** (Real Power) and **VARs** (Reactive Power)  
result in **VA** (Apparent Power)



163

## Hot Line Work



164

## Resistors

### Resistance depends on:

#### Resistivity

Conducting material has low resistivity, insulators have high resistivity

#### Length

Decreasing the material's length decreases the resistance

#### Cross-sectional area

Increasing the material's cross-sectional area decreases the resistance

#### Temperature

The hotter the wire, the more resistance it exhibits

165



166

## Capacitors

Capacitors are used to **INCREASE** voltage

### Capacitance (C)

Opposes change in voltage

Unit of Measurement: **Farads (F)**

Stores electrical charge

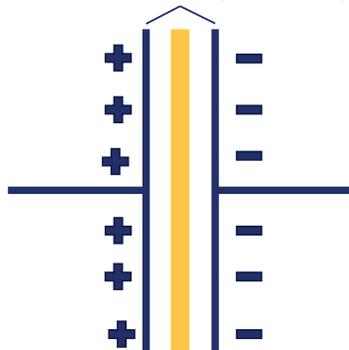
Two metal plates separated by an insulating sheet of material

Flow of current builds charge on the plates

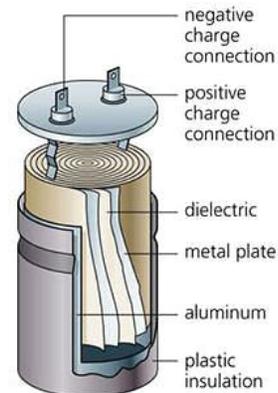
167

## Capacitors

### Conducting Plates (electrodes)



Insulating Dielectric



A common capacitor design

168



169

## Distribution Switched Capacitor Bank



170

## Substation Capacitor Bank



171

## Inductors

### Inductors are used to **REDUCE** voltage

#### Inductance (L)

Opposes change in current

Unit of Measurement: **Henry (H)**

A coil of wire or long transmission line

Provides inductance or reactance

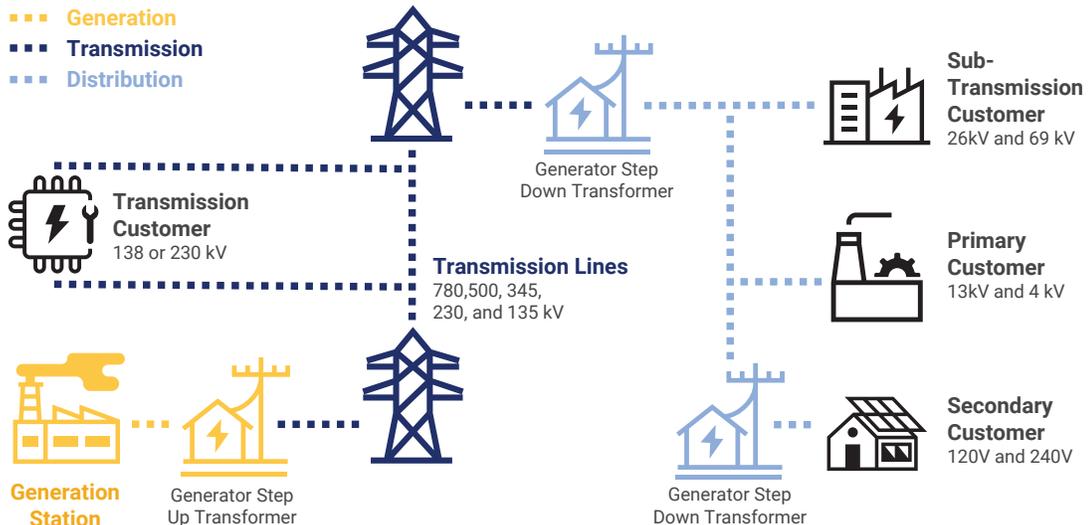
172

## Shunt Reactor



173

## The Electrical System Structure



174



# Section 4.4 – Loads

Mark Willis

Principal Risk Engineer



## Power

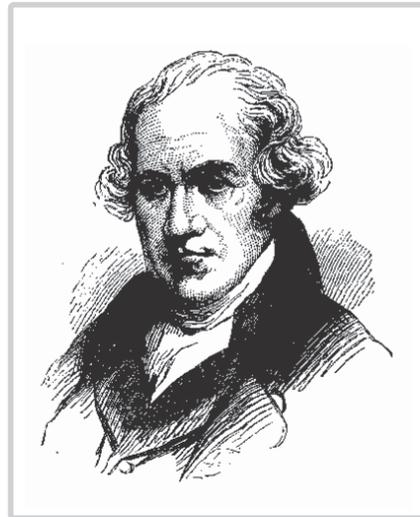
Named after:  
**James Watt**



Time Period: **1736–1819**      Unit of measurement: **Watts (W)**

What is it?  
**The rate at which work is being performed**  
**Power = Voltage x Current**

- Electrical energy converted to heat, light, mechanical energy, etc.
- A “watt” is instantaneous value, it is the power being used at any given time



## Power

### Sample Power Calculation

A toaster uses **120 volts** with **10 amps** of current.

How much power does it consume?

### Formula for Power

Power (P) = Volts (V) \* Current (I)

We measure power in Watts (W)

$$P = (120) * (10)$$

$$P = \underline{1,200}$$

Answer

**1,200 Watts (W)**



## How much power are we consuming during an average morning?

What appliances do you have turned on?

Appliance	Power Usage
100W light bulb (Incandescent)	100W
46 Inch LED TV	70W
60W light bulb (Incandescent)	60W
65 Inch LED TV	130W
Amazon Echo	3W
Ceiling Fan	70W
Coffee Maker	1400W
Computer Monitor	30W
Cooker Hood	30W
Electric Kettle	3000W
Electric Mower	1500W
Electric Pressure Cooker	1000W
Electric Shaver	20W
Electric stove	2000W
Electric Tankless Water Heater	8800W
Food Blender	400W
Fridge / Freezer	400W
Deep Fryer	1000W

Appliance	Power Usage
Guitar Amplifier	30W
Hair Blow Dryer	2500W
Home Air Conditioner	4000W
Inkjet Printer	30W
Inverter Air conditioner	1800W
Iron	1000W
Laptop Computer	100W
Microwave	1700W
Night Light	1W
Outdoor Hot Tub	500W
Oven	2150W
Playstation 4	90W
Electric Shower	10500W
Pressure Cooker	700W
Projector	270W
Rice Cooker	800W
Treadmill	900W
Vacuum Cleaner	900W
Washing Machine	500W
Water Feature	35W

183

# Energy

## A "Watt" Is Instantaneous Value:

The power being used at a given time

A "Watt-hour" indicates how much energy is used over an hour

## Formula for Energy

$$\text{Watts (W)} * \text{Time (in hours)} = \text{Energy (Watt-hours)}$$



184

# Energy

## The Sum of Power Delivered Over a Period

Unit of Measurement: Watt-Seconds or Joules (J)

- This is too small for utility applications where energy is typically measured in thousands of **watt-hours or kWh**

## Formula for kWh

$$\text{Kilowatts (kW)} * \text{Time (in hours)} = \text{Kilowatt hours (kWh)}$$

## How many kWh is 5,000 watts used for 3 hours?

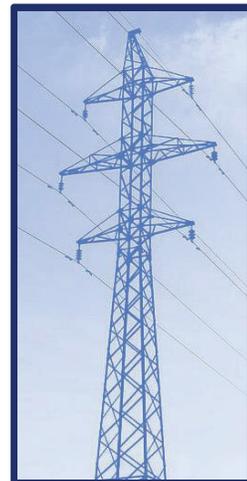
Conversion: 5,000 Watts (W) = 5 kW

$$(5\text{kW}) * (3 \text{ hours}) = \text{kWh}$$

$$\text{kWh} = 15$$

Answer

**15 kWh**



185

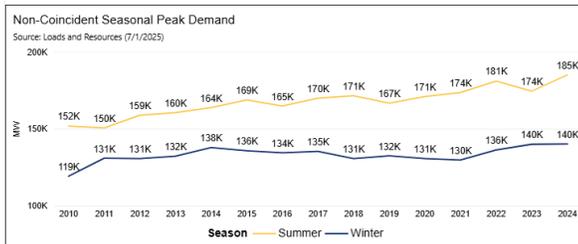
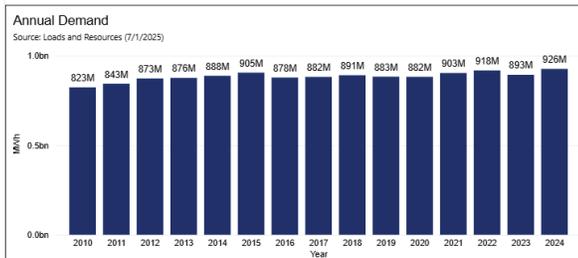
# NERC

NORTH AMERICAN ELECTRIC  
RELIABILITY CORPORATION

## Load:

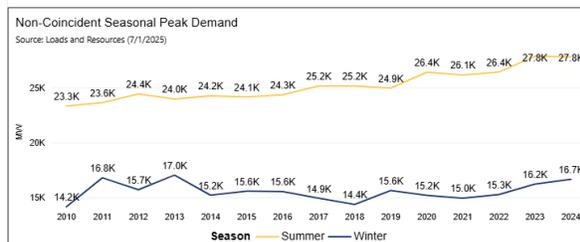
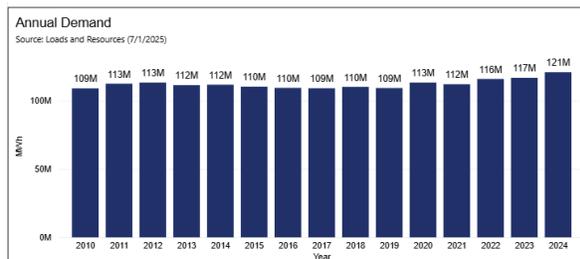
An end-use device or customer that receives power from the electric system.

## System Demand – WECC



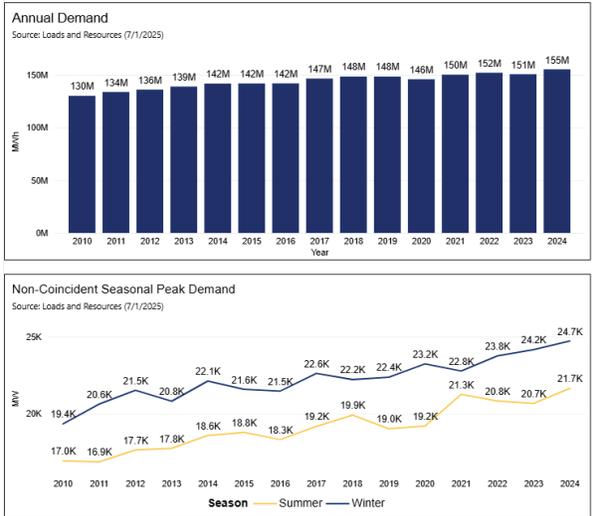
Note: Hour of peak demand for each BA, Region, and Interconnection may not be coincident.  
CISO is the total of CIPB, CIPV, CISC, and CISD.  
IPCO is the total of IPFE, IPMV, and IPTV.

## System Demand – Southwest



Note: Hour of peak demand for each BA, Region, and Interconnection may not be coincident.  
CISO is the total of CIPB, CIPV, CISC, and CISD.  
IPCO is the total of IPFE, IPMV, and IPTV.

# System Demand – Canadian Entities <Limited-Disclosure>

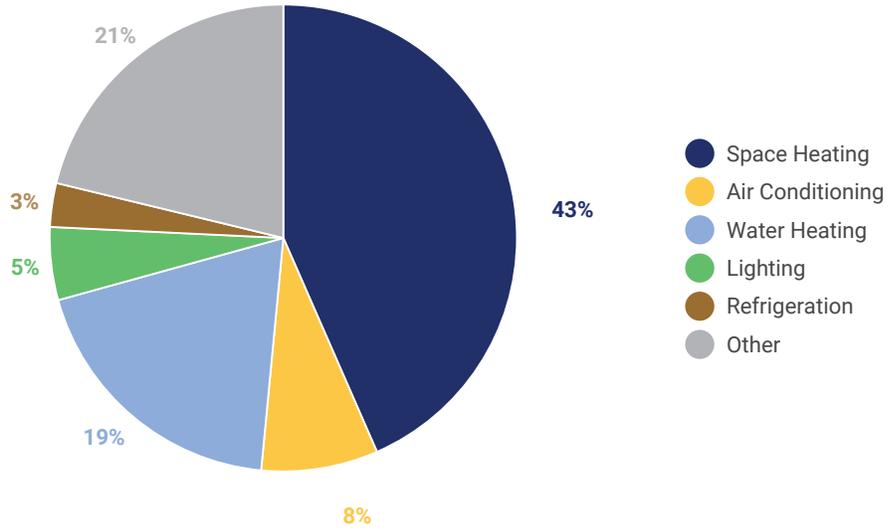


## Canadian Entities



Note: Hour of peak demand for each BA Region, and interconnection may not be coincident.  
 CISO is the total of CIPB, CIPV, CISC, and CISD.  
 IFCO is the total of IPFB, IPMV, and IPTV.

# Energy Use For an Average U.S. Home

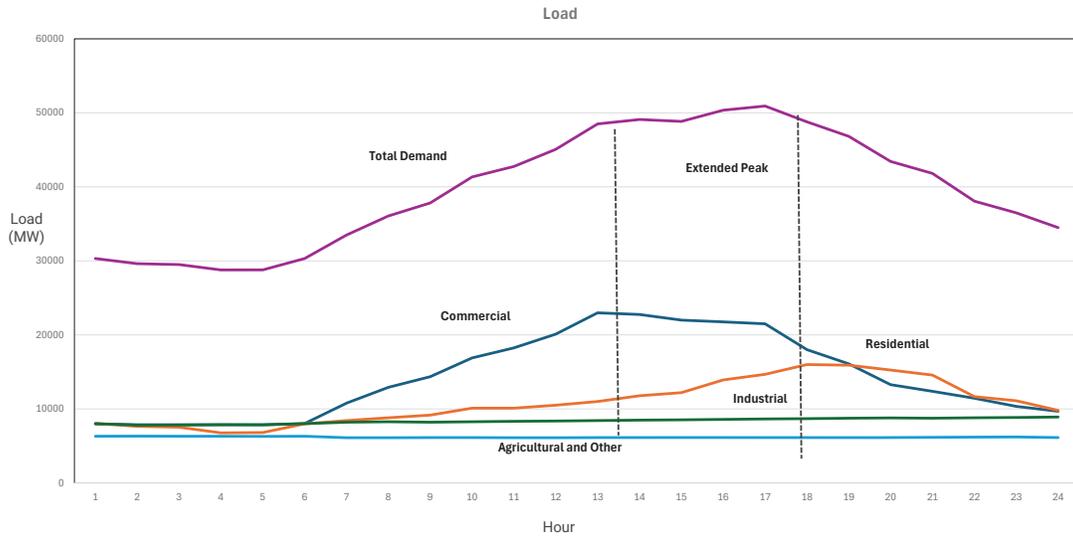


# Types of Load



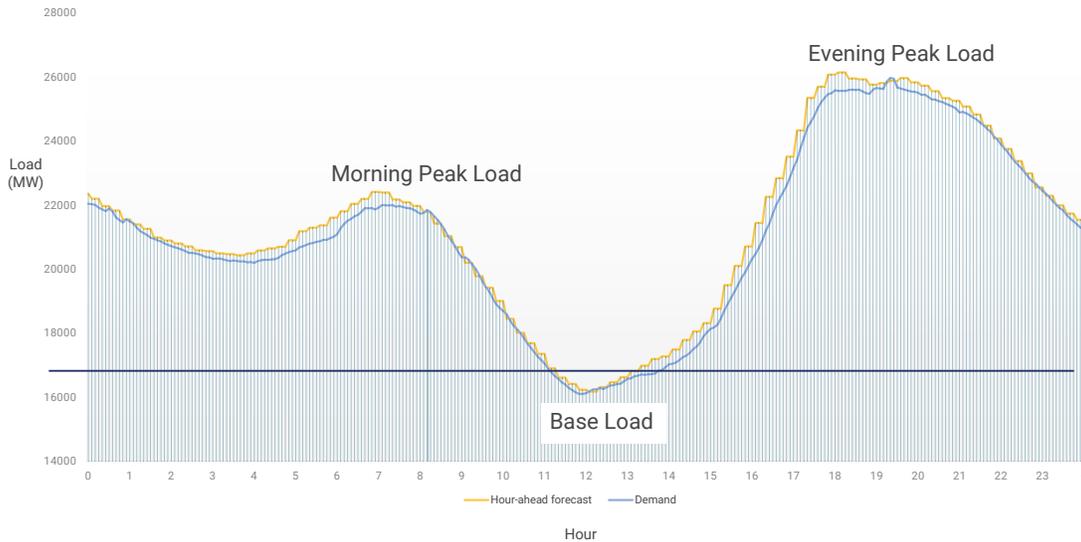


# Hourly Load – Varies by Customer Type <Limited-Disclosure>



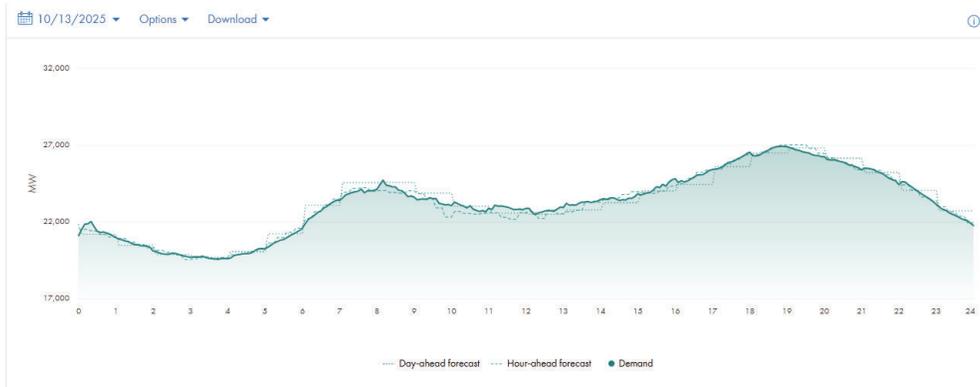
195

# Base Load and Peak Load

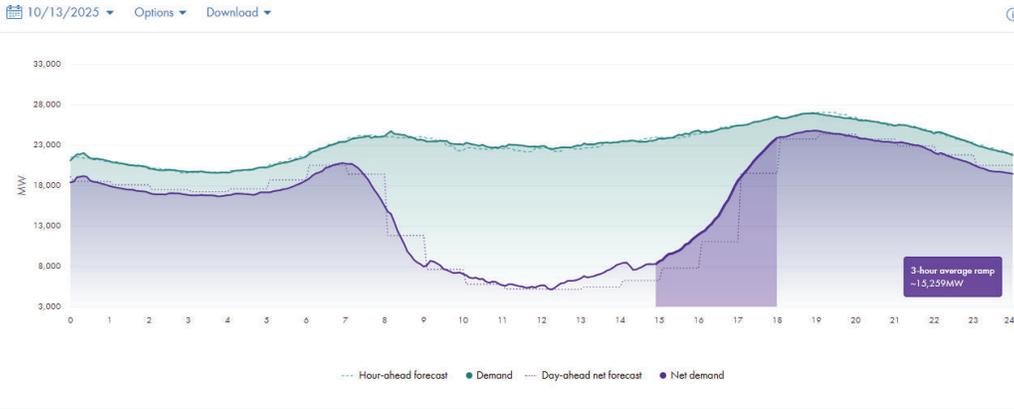


196

# Typical Load Curve



197



## Forecasting Load

Forecast	Time	Use
Very Short	Seconds to minutes	Generation, distribution, operations analysis
Short	Minutes to hours	Unit commitment, maintenance scheduling
Medium	Days to weeks	Seasonal Peaks
Long	Months to years	Generation/Growth

## The Power Grid (1)

**CREDC**  
CIVIL RESILIENT ENERGY DELIVERY CONSORTIUM

Education

INTERACTIVE ACTIVITIES... RESOURCES MINECRAFT... ABOUT...

Home • Interactive Activities

### The Power Grid

**Description:**

The power grid is the system of producers and consumers of electricity. It includes power generators, the users of electricity, switches that control the electricity, and the system of substations, power lines, and transformers that deliver the electricity. A community might have a generator to provide its power. The generator may be able to vary its production as the usage of the customers changes, but there may be times when the demand for energy is too great for the generator. Then the community buys electricity from another source. At other times, the generator may be making more electricity than the community is using, so it wants to sell it.



<https://credc.mste.illinois.edu/applet/pg#>

### All Power Grid components operate together as one system:

- Generation – Coal, Hydro, Natural Gas, Nuclear, Solar, Wind, Other
- Transmission – Lines, Substations
- Loads – Residential, Industrial, Commerce
- External Neighboring Entities (Balancing Authorities, Transmission Operators)

206

## The Power Grid – Grid Status

### Status:

- Generation = 1,000 MW (Hydro), 200 MW (Wind), 0 MW (Nuclear), 600 MW (Coal), 200 MW (Natural Gas) = 2,000 MW Total
- Load = 500 MW (Res), 100 MW (Industry), 300 MW (Comm) = 900 MW Total
- Interchange = 549 MW + 549 MW = 1100 MW
- Generation MW + Interchange MW = Load MW
- Balanced System! (60 Hz)

207

## The Power Grid – Scenario 1 – Adding Generation

- First press the "Reset System"
- Then, close the "blue switch" to the left of the Nuclear Power Plant (900 MW)
- **What happens to the grid?**
  - Additional generation (900 MW) added
  - If the other resource outputs don't change, and the load remains the same, what changes?

208

- First press the "Reset System"
- Then, increase each of the three loads by the following:
  - Residenceburg to 1,800 MW
  - Industryville to 400 MW
  - Commerceton to 900 MW
- What happens to the grid?
  - Hints: Change in "arrow colors" and External Systems
  - Close the "blue switch" to the left of the Nuclear Power Plant (900 MW)
    - Did any "arrow colors" change? If not, why not?
    - Did the flows change with the External Systems?

209

## The Power Grid – Scenario 3

---

- First press the "Reset System"
- Then, open the "blue switch" to the External System 1 and the External System 2
- **What happens to the grid?**
  - Why did this happen?
  - "Reset System" again, and look at the flows to both External Systems
  - What action would possibly mitigate this?

210

## The Power Grid – Homework

---

- **Challenges:**
  - On your own, work through Challenges 2–5 for discussion tomorrow morning
  - Have fun!

211

<Limited-Disclosure>



[WWW.WECC.ORG](http://WWW.WECC.ORG) | (801) 582-0353



155 N 400 W, Salt Lake City, UT 84103, USA



# Section 1 – BPS Disturbances

**Mark Willis**  
*Principal Risk Engineer*

**Donovan Crane**  
*Senior Engineer*

5



## The Bulk Power System

- [NERC](#): (A) facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof); and
- (B) electric energy from generation facilities needed to maintain transmission system reliability.

The term does not include facilities used in the local distribution of electric energy. (Note that the terms "Bulk-Power System" or "Bulk Power System" shall have the same meaning.)

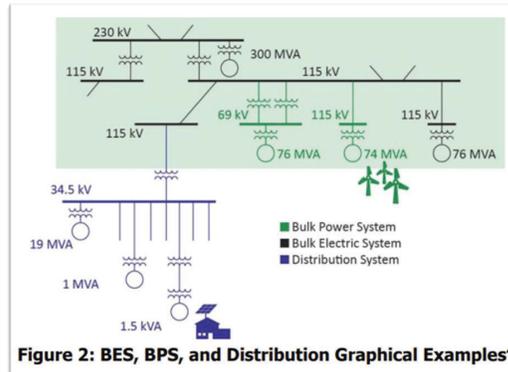
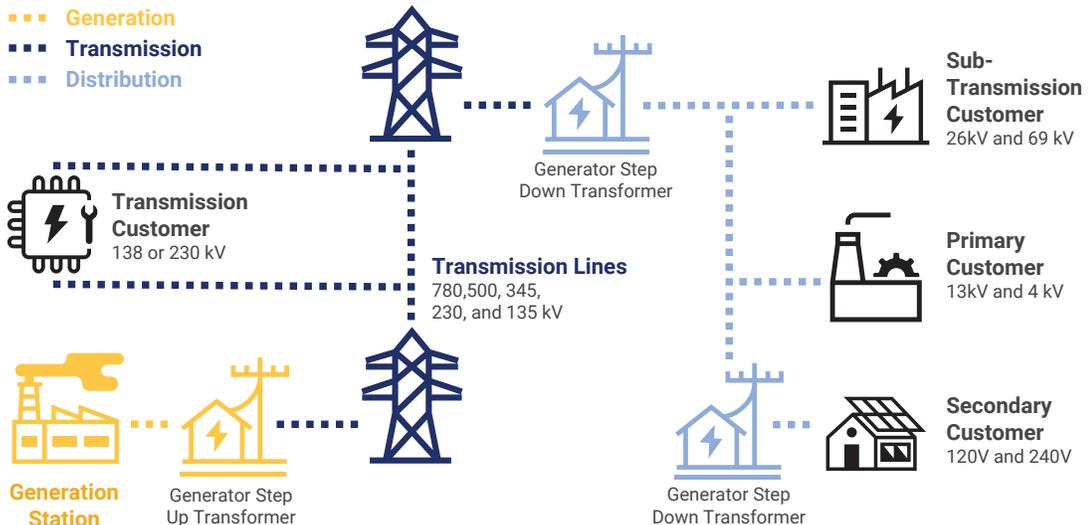


Figure 2: BES, BPS, and Distribution Graphical Examples'

6



## The Electrical System Structure



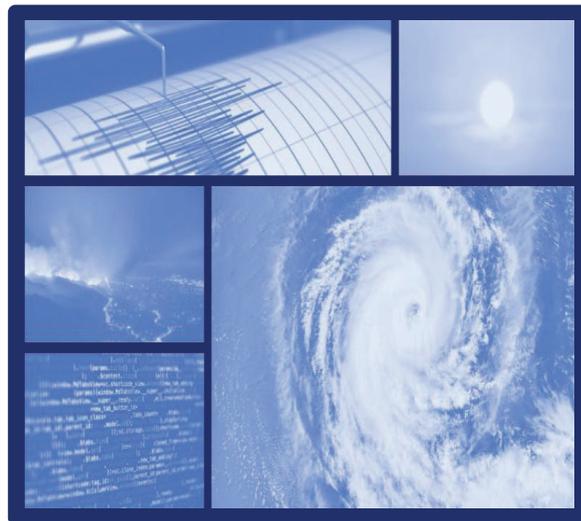
7

- Load shedding
- Generation tripping
- Full or partial blackout
- Uncontrolled separation
- Cascading

8

## What Causes a Major Disturbance?

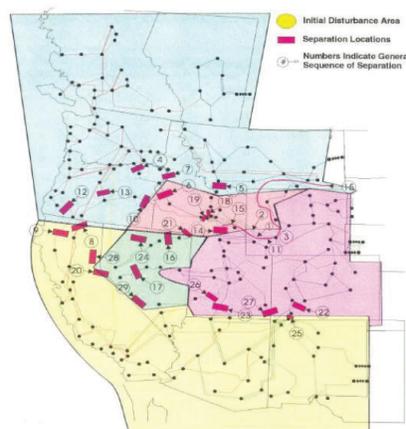
- Vegetation
- Equipment malfunction
- Inadequate system
- Operating errors
- Sabotage
- Combination of events (“perfect storm”)
- Storms
- Earthquakes
- Fires



9

## 1996 July WSCC System-Wide Disturbance

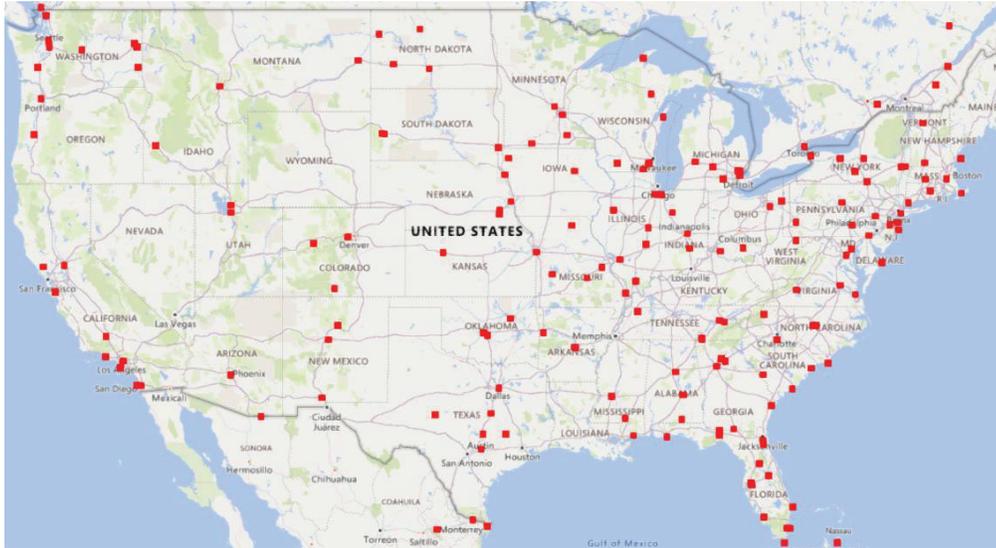
### Sequence of System Separations



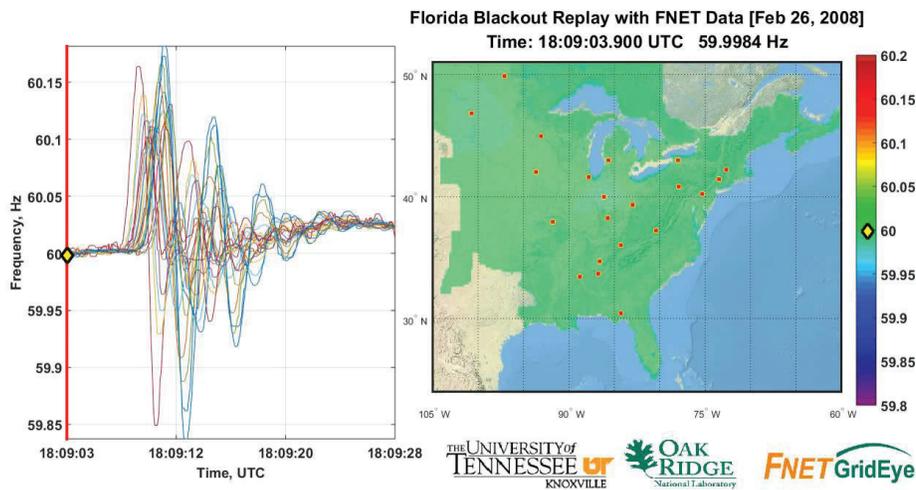
Islands Formed -- July 2, 1996

10





## 2008 Florida Blackout—FNET Frequency Display



## September 8, 2011

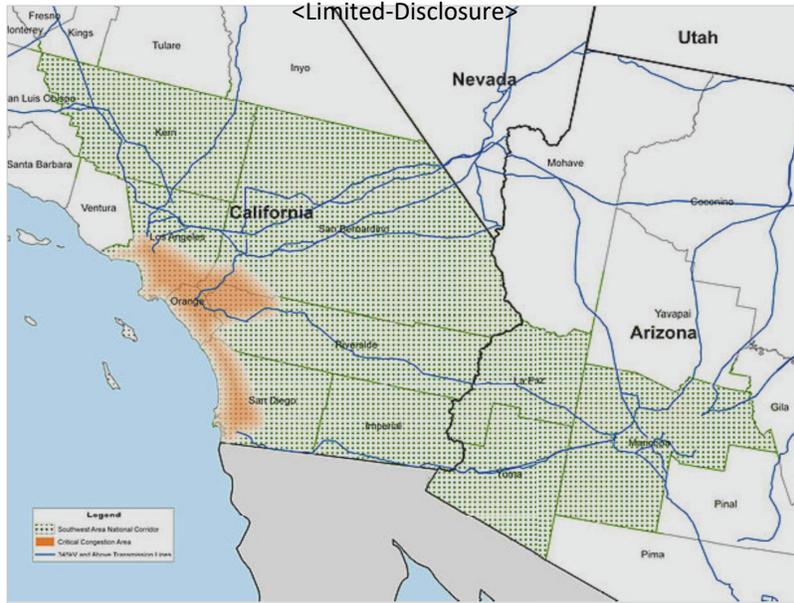
**Initiating event:**

- 500 kV line
- Due to an operating error
- A hot summer day

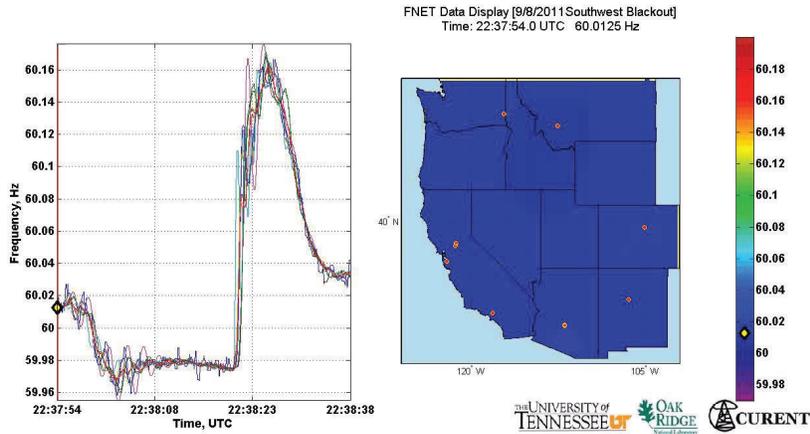
**Outcome:**

- Complete outage for San Diego and southwest Arizona
- Five utilities lost load
- 2.7 million customers
- All load was restored in about 12 hours

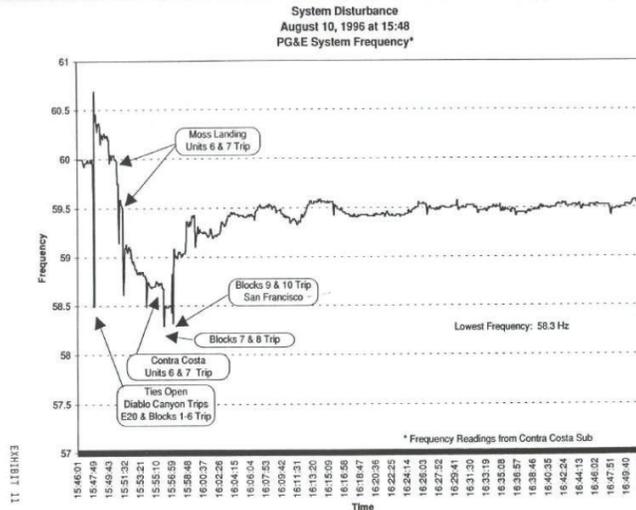
Load Interrupted:	
SDG&E	4,293 MW
CFE	2,150 MW
IID	929 MW
APS	389 MW
WALC	74 MW



## Frequency Response Display



## 1996 August WSCC System-Wide Disturbance



### FERC/NERC Report Findings

The system was not being operated in a secure state for an N-1 outage due to:

- Lack of information sharing between entities
- Lack of adequate studies
- Sub-100-kV facilities not adequately considered in next-day studies

20

### Some NERC Standards Violated

#### COM-002

- Issue directives in a clear and concise manner
- Three-part communication

#### EOP-001

- Developing, maintaining, and implementing emergency plans

#### EOP-003

- Shed load rather than risking uncontrolled failure or cascade

#### EOP-005

- Returning system to normal following a disturbance

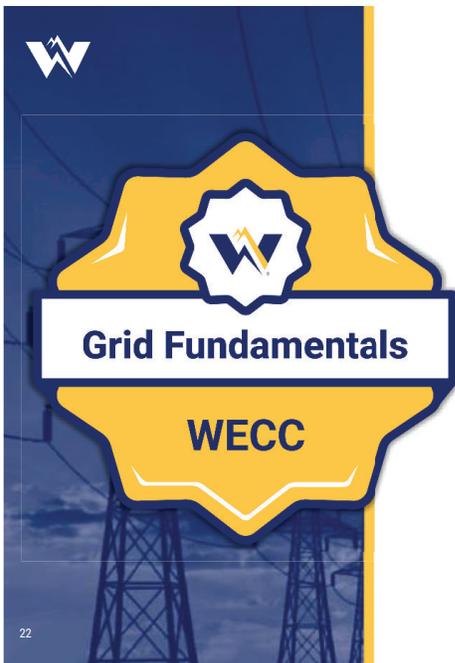
#### EOP-006

- Coordination with Reliability Coordinator

#### TOP-004

- Operate so that instability, uncontrolled separation, or cascading outages will not occur as a result of the most severe single contingency

21



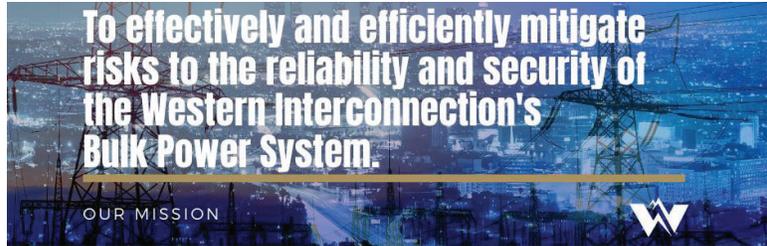
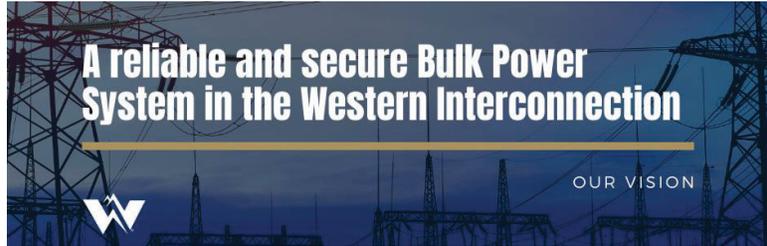
## Section 2 – Reliability

Mark Willis  
*Principal Risk Engineer*

22



<Limited-Disclosure>



23



## Essential Reliability Services

- [NERC Essential Reliability Services](#)
- [Keeping the Lights On: Essential Reliability Services | Department of Energy](#)
  - Frequency (Frequency Response)
  - Ramping (and Balancing)
  - Voltage (Support and Control)

24



## Why are nominal (normal) Frequency and Voltage important?

Both nominal (60 Hz) frequency  
and  
nominal (120/240 V, etc.) voltage  
ensures that equipment is not damaged,  
such as generators, motors, and equipment of all sizes and types

25

- **Frequency Response (NERC Definitions):**
  - *(Equipment) The ability of a system or elements of the system to react or respond to a change in system frequency.*
  - *(System) The sum of the change in demand, plus the change in generation, divided by the change in frequency, expressed in megawatts per 0.1 Hz (MW/0.1 Hz).*
  - Ability of the power grid to continuously operate at 60 Hz (60 cycles per second)
  - Deviates from 60 Hz for changes in generation and/or load
  - Generation responds to maintain ~60 Hz
  - Both automatic and manual controls are used to maintain 60 Hz

26

## Balancing

- **Balancing (Services): Related to frequency response, but longer timeframe (minutes and beyond).**
  - Ability to ramp generation to match the load and generation at all times
  - Results in maintaining system frequency at 60 Hz
  - Two parts regarding balancing:
    - Minute-to-minute as generation and load changes
    - Future planning for forecasted loads, generation changes, schedule changes, scheduled maintenance, etc.

27

## Voltage Control

- **Voltage Control: Must be controlled in both normal and contingency conditions (loss of a generator, transmission line, etc.)**
  - Controlled by adjusting the reactive power utilizing generators, capacitors, and inductors
  - Reactive Power (MVar) supports the Real Power (MW)

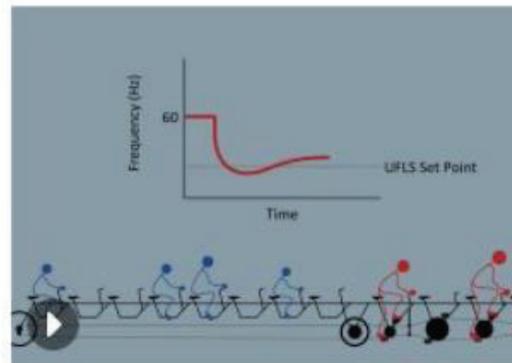
28

# THE BASICS OF ESSENTIAL RELIABILITY SERVICES



## Essential Reliability Services – Frequency

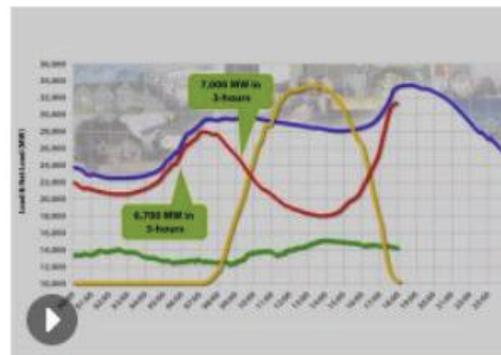
- [The Basics of Essential Reliability Services – Frequency](#)



Frequency

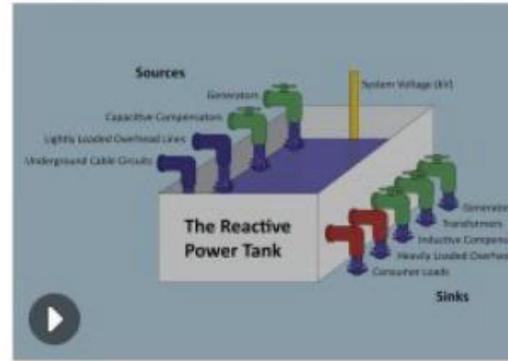
## Essential Reliability Services – Ramping

- [The Basics of Essential Reliability Services – Load Ramping](#)



Load Ramping

- [The Basics of Essential Reliability Services – Voltage](#)



Voltage



## Section 3 – Compliance

**Donovan Crane**  
*Senior Engineer*

## Regulatory Relationships

	<p><b>FERC</b></p> <ul style="list-style-type: none"> <li>• Oversees NERC via 2005 Energy Policy Act</li> <li>• Approves NERC standards and NERC-approved violation dispositions</li> </ul>
	<p><b>NERC</b></p> <ul style="list-style-type: none"> <li>• Delegates enforcement authority to regional Entities via FERC-approved agreements</li> <li>• Approves violation dispositions from Regional Entities</li> <li>• Develops standards with industry input</li> </ul>
	<p><b>Regional Entities</b></p> <ul style="list-style-type: none"> <li>• Monitoring Registered Entities with authority to find violations and levy financial penalties/sanctions for non-compliance</li> <li>• May participate in standard development process</li> </ul>
	<p><b>Registered Entities</b></p> <ul style="list-style-type: none"> <li>• Responsible for compliance with NERC standards</li> <li>• Responsible for demonstrating programs/compliance that focus on reliability and security of the Bulk Power System.</li> <li>• May participate in standards development process.</li> </ul>

## Continent-wide Risks



## Interconnection Risks



## Regional Risks

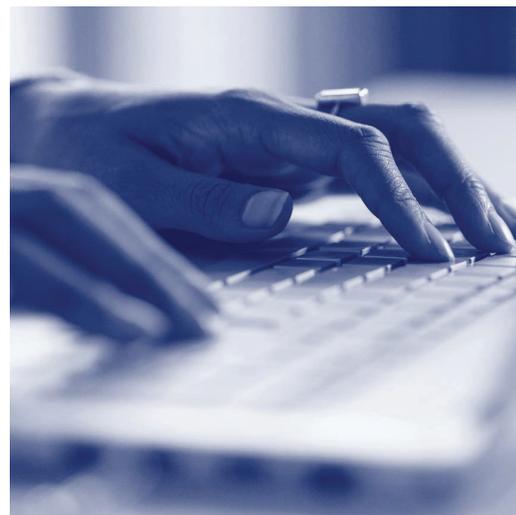
Entity Inherent Risk  
Entity Performance Risks

41



42

- Each Regional Entity (e.g., WECC) maintains and implements a program for risk-based compliance monitoring
- The most common compliance monitoring methods include:
  - Compliance Audits
  - Spot Checks
  - Self-Certifications
  - Periodic Data Submittals
- Findings



43



<Limited-Disclosure>



## Section 4 – Reliability & Organized Wholesale Markets

Mark Willis  
*Principal Risk Engineer*

44



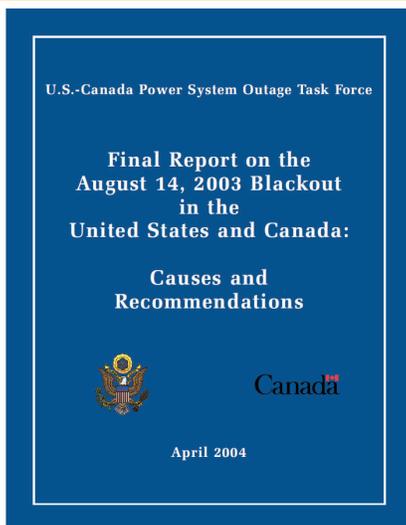
### Reliability (1)

- Reliability – [History book](#)
- From “Good utility practice” to Federal Mandatory & Enforceable Reliability Standards
- *Why the change?*
  - 1996 Western Interconnection Disturbances (July & August)
  - 2003 East Coast Blackout (August) – 50 M out of power

45



### Reliability (2)



46

- Energy Policy Act (EPA) 2005 – Title XII – Electricity; Subtitle A-Reliability Standards; Sec. 1211. Electric reliability standards ([Energy Policy Act 2005](#)) – Addressed in five pages of the 551-page Act
  - Amended Part II of the Federal Power Act (1920)
- June 18, 2007 – FERC Mandatory & Enforceable NERC Reliability Standards

47

## What entities are involved?

- NERC Functional Entities:
  - RC, BA, TOP, TO, GOP, GO, LSE, DP
- Types of Electric Utilities:
  - Investor-Owned Utility (IOU), Public Owned Utility (POU) (PUD, Municipal Utility District, Irrigation District, Rural Electric Cooperative), Power Marketing Agency (PMA), etc.
- Independent Power Producers (IPPs)
- Transmission Company (Transco)
- Market Operators:
  - Regional Transmission Organizations (RTO), Independent System Operators (ISO)
- Market Participants:
  - IOUs, Municipalities, energy commodity brokers, etc.

48

## How do these work together?

- NERC Registered Entities – responsible for the compliance of the NERC Reliability Standards and other related reliability obligations:
  - Essential Reliability Services – Frequency, Balancing, Voltage
  - Reserve Sharing Groups
  - Etc.
- Market Operators – responsible for the implementation of their Market Tariff (FERC)
- Market Participants – responsible for adherence to the Market Tariff, associated Business Practices, etc.

49

- Bilateral Markets
  - Governed by Western Systems Power Pool (WSPP) Agreement – Filed by PG&E with FERC in 1986 – 14 original members, now over 350 members
  - Allowed sales of power for short-term transactions
  - Between Two Parties
  - Power Purchase Agreements (PPAs) – varying contractual length
  - Capacity / Energy / Ancillary Services / Return Energy / etc.

50

## Wholesale Electric Energy (2)

---

- Organized Wholesale Markets
  - Centrally dispatched generation and coordinates transfers of wholesale electricity
  - Day-Ahead, Hour-Ahead, & Real-Time Market segments
  - Energy / Ancillary Services / Congestion Revenue Rights / Virtual (Convergence) Bidding
    - Ancillary Services: Frequency Reserve, Regulation Up/Down, Spinning Reserve, Non-Spinning Reserve
  - Locational Marginal Prices (LMP)

51

## Organized Wholesale Markets (1)

---

- [An Introductory Guide to Electricity Markets regulated by the Federal Energy Regulatory Commission \(FERC\)](#)
- Western Energy Markets ([Western Energy Markets Explainer | Federal Energy Regulatory Commission](#))

52

- Timeline of Major FERC Orders – Electric
  - Order No. 888 (4/24/1996) – Transmission Open Access. Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Service by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmission Utilities
  - Order No. 889 (4/24/1996) – OASIS: Open Access Same Time Information System (formerly Real-Time Information Networks) and Standards of Conduct (SoC)

53

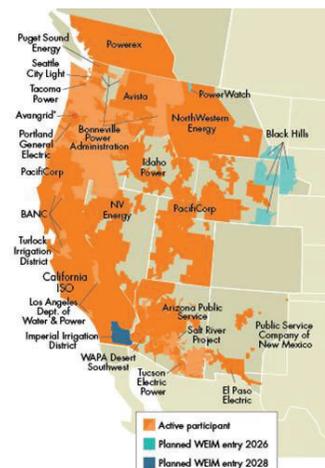
## Organized Wholesale Markets (3)

- Timeline of Major FERC Orders – Electric
  - Order No. 2000 (12/20/1999) – Regional Transmission Organization (RTO) Encourage public utilities to join an RTO
  - Order No. 2222 (9/17/2020) – Participation of Distributed Energy Resource Aggregations in Markets Operated by RTOs and ISOs

54

## California ISO Energy Imbalance Market (EIM)

- Real-time bulk power trading market
- Automatically finds the lowest-cost energy
- Serves real-time customers across wide geographic area
- Improves use of renewable energy

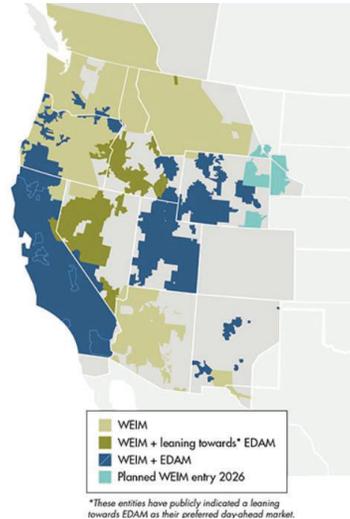


\*Avangrid office; generation only BAA with distribution across multiple states. Map boundaries are approximate and for illustrative purposes only. Copyright © 2023 California ISO

55

## California ISO Extended Day-Ahead Market (EDAM) <Limited-Disclosure>

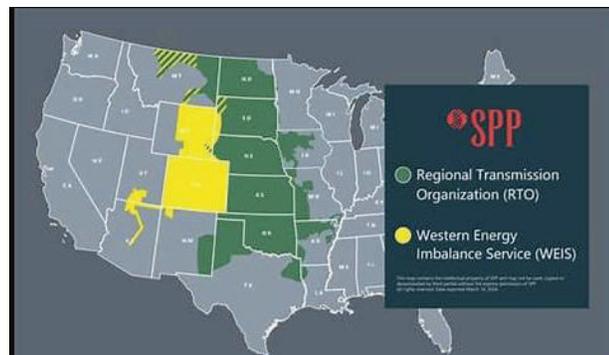
- Voluntary day-ahead market
- Deliver significant reliability, economic, and environmental benefits
- Go-live expected 2026



56

## Southwest Power Pool Energy Imbalance Market Services (EIS)

- Real-time bulk power trading market
- Automatically finds the lowest-cost energy
- Serves real-time customers across wide geographic area
- Improves use of renewable energy



57

## Southwest Power Pool Markets+

- Bundle of services
- Centralized day-ahead and real-time unit commitment and dispatch
- Reliable integration of renewable generation
- Enhances reliability, increases participant value, equitably compensates participants and incorporates their diverse perspectives



58

- Types of Markets:
  - Bi-Lateral Market
  - Energy Imbalance Market – Real-Time
  - Fully Integrated Market – Day-Ahead and Real-Time
- Generation sources sell power
- Load entities buy power

59

## Bi-lateral Markets

- Interchange energy is exchanged by bi-lateral energy transactions on (typically) hourly schedules
- Agreement between (typically) two parties per WSPP
- Physical trading energy with transmission reservation and “tagging” the resource from source to sink and the transmission segments
- Energy transactions can be firm / non-firm, and a single hour to daily, monthly, yearly, multi-year
- Load is self-supplied or supplied from bi-lateral transaction

60

## Organized Wholesale Markets – Energy Imbalance Markets (1)

- Energy Imbalance – Actual Production/Usage vs. Scheduled Production/Usage
  - Differences comes from:
    - Generation scheduled vs. actual output
    - Load forecast vs actual
- Security Constrained Economic Dispatch (SCED)
  - Economically dispatch generation to meet demand while adhering to all constraints (generation limits, transmission limits, etc.)
- Market Operator uses SCED to dispatch (up or down) the next most economic generator(s) to meet the energy imbalance

61

## Organized Wholesale Markets – Energy Imbalance Markets (2)

<limited-Disclosure>

- Each BA remains responsible for scheduling and serving their load
- 15-minute and five-minute increments in real-time
- Geographic and resource diversity in a large footprint is beneficial
- Lowest cost resources are utilized for the imbalance
- Resources bid into the market with a bid curve that allows the resource to increase or decrease production at a cost/MW
- Both supply (generators) and demand (load) bid into the market
  - Generators – bid what they are willing to be paid to generate
  - Load – bid what they are willing to pay to serve their load

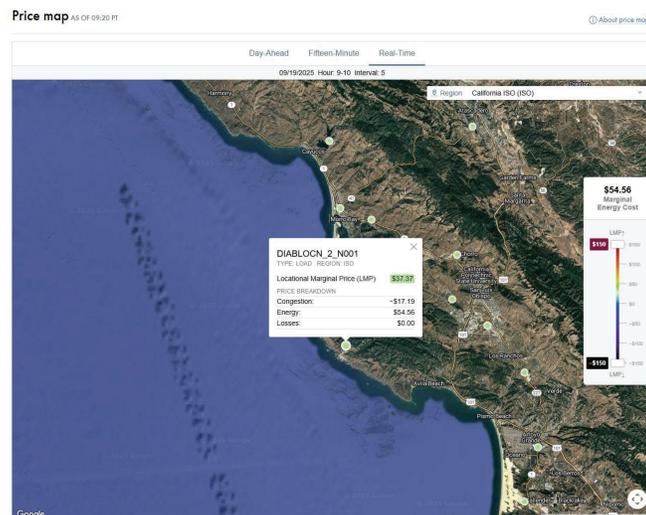
62

## Organized Wholesale Markets – Energy Imbalance Markets (3)

- Currently, excess transmission available in real-time is allowed to be utilized by participating Energy Imbalance entities at zero cost
  - Note: This is transmission capacity not reserved for native load, etc.

63

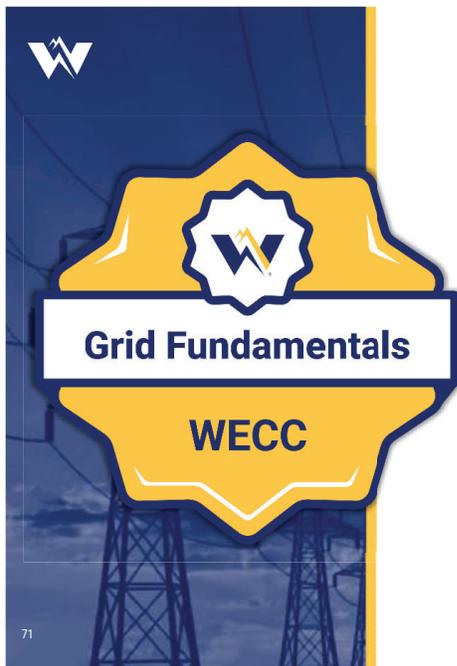
## Organized Wholesale Markets – Energy Imbalance Markets (4)



64

- Market benefits:
  - Economies of scale
  - Reserve sharing
  - Variable energy integration
  - Coordinated planning
  - Efficiency
  - Market transparency

65



## Section 5 – Risks to the BPS

Mark Willis  
*Principal Risk Engineer*

## Risks to the BPS

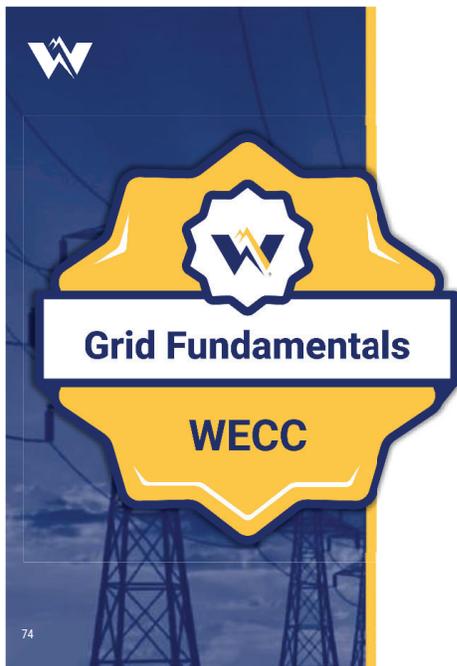
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- [NERC 2025 State of Reliability – Technical Assessment](#)
- **Identified Risks:**
  - Energy Policy – Changes in BPS planning and operations, affecting reliability and resilience
  - Grid Transformation – Energy sufficient in planning and operating the grid
  - Resilience to Extreme Events – Extreme natural events
  - Security Risks – Increasing cyber and physical security threats
  - Critical Infrastructure Interdependence – Available generation with on-site or firm fuel capacity

72

- Categories of Risks include:
  - Cybersecurity
  - Extreme Natural Events
  - Frequency Performance
  - Grid Transformation
    - Inverter-based Resources
    - Resource Adequacy
    - Changing Resource Mix
  - Infrastructure
  - Personnel
  - Physical Security
- [WECC Risk Register](#)

73



74

## Section 6 – Grid Transformation Technology

**Donovan Crane**  
*Senior Engineer*

### Grid Transformation Technology

- Conventional generation (synchronous) to inverter-based generation (non-synchronous)
- Inverter-based Resources (IBR)
  - Grid Following
  - Grid Forming
- Load Types
  - Data Centers – Computational Load / Artificial Intelligence Training / Cryptocurrency mining
  - Industrial – Mining/mineral, Metals/heavy manufacturing, Semiconductor/electronics, Chemical/petrochemical, Oil/gas
  - Hydrogen Production (electrolysis)

75

## How do these changes affect the grid? <Limited-Disclosure>

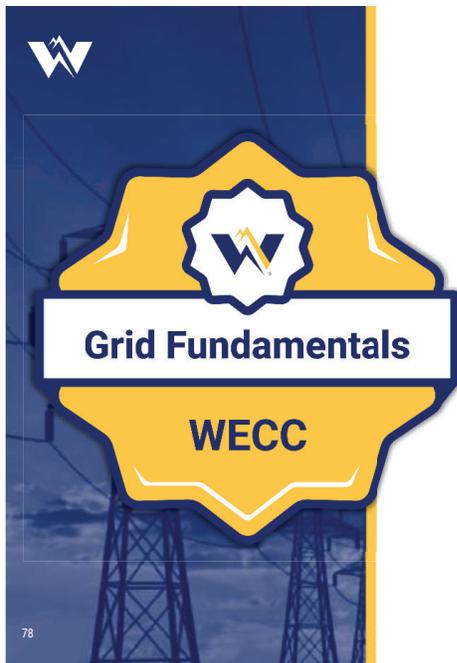
- IBR Generation:
  - Inertia – IBR generation does not have inertia (no spinning rotors)
  - Variable generation (solar/wind) changes/ramping
- Loads
  - Less predictable
  - Concentrated locations
  - Varying ramping magnitudes and times
  - Demand side management programs (Time of Use, EV Charging, etc.)

76

## Essential Reliability Services

- Recall...Frequency Response...Balancing / Ramping...Voltage Control
- Challenges continue to grow to reliably operate the grid with significant changes to both the resources (generation) and demand (load)

77



# Section 7 – System Operations

**Mark Willis**  
*Principal Risk Engineer*

**Donovan Crane**  
*Senior Engineer*

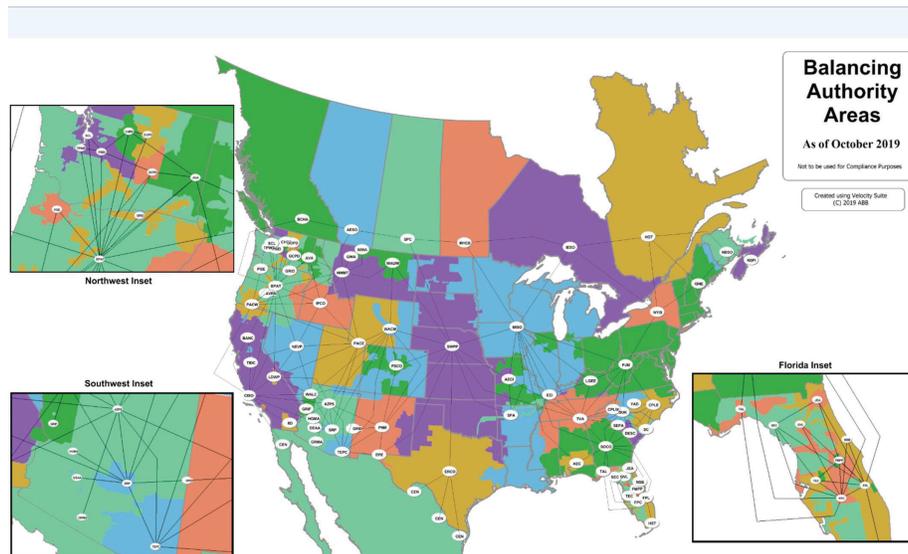
78

- **Reliability Coordinators**
  - Highest level of authority responsible for the reliable operation of the Bulk Electric System with a wide area view
- **Balancing Authorities**
  - Responsible for maintaining the balance of electric power within a specific area
- **Transmission Operators**
  - Responsible for the reliability of its transmission system and operating or directing the operations of the transmission facilities
- **Generator Operators**
  - Responsible for operating its generating facilities or directs the operation of generating facilities



79

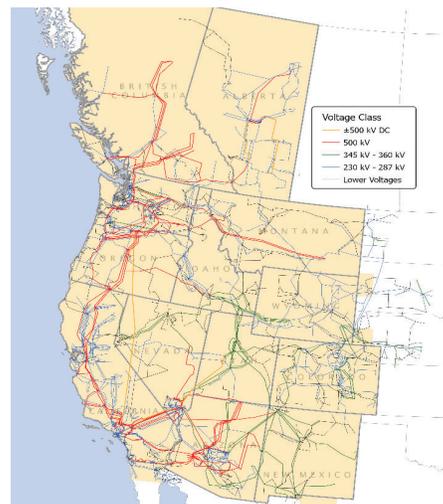
## Balancing Authority Areas



80

## Transmission Operators

- 52 Transmission Operators
- Over 158,000+ miles of transmission lines



81



82

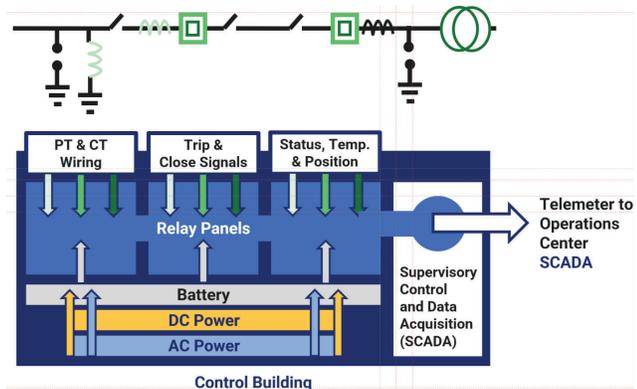
## Control Center – CAISO



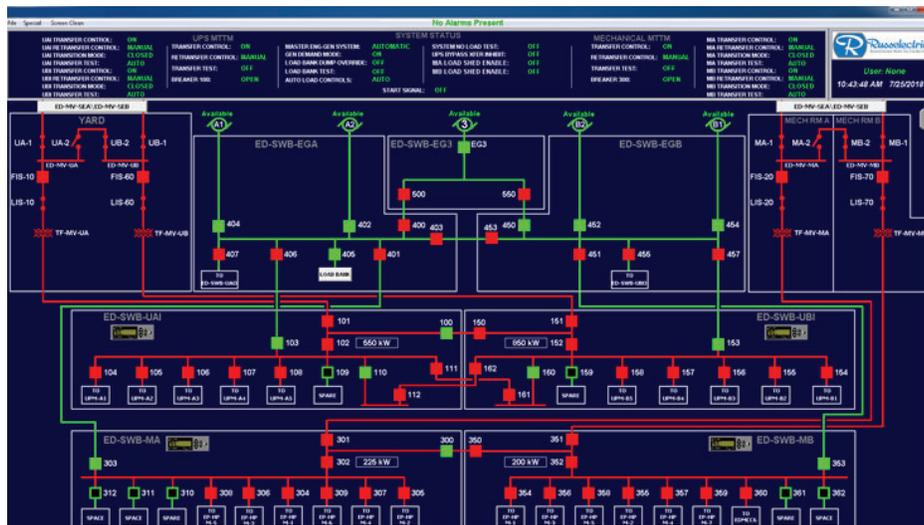
83

## Control Center Operations

- SCADA (Supervisory Control and Data Acquisition)
- Alarms
- Generator/Equipment status
- Breaker and line status
- Power Flow/Voltages
- System loads



84



85

## SCADA-Desktop



86

## Control Center Operations

## Energy Management System (EMS)

- Supervisory Control and Data Acquisition (**SCADA**)
- Alarm Processing
- Automatic Generation Control (**AGC**)
- State Estimator (**SE**)
- Real-Time Contingency Analysis (**RTCA**)

## Situation Awareness



87



88

## System Operating Limits

### Based On Thermal Or Voltage Limits

- SCADA provides current values and alarms on limit violations

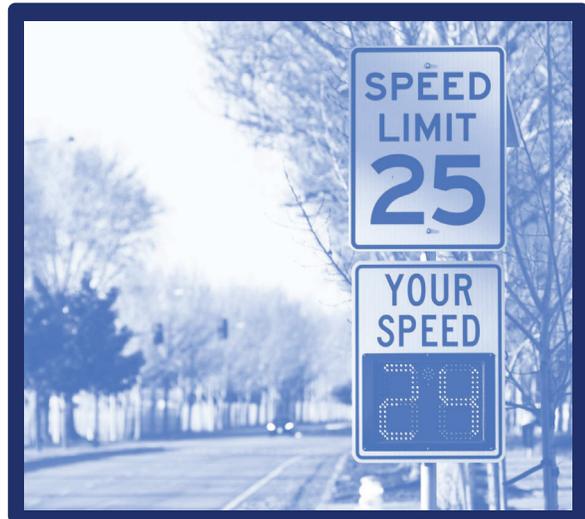
### Load Limits—protect Transmission

- Excessive power flow can cause heating above equipment limits

### System Stability—protects Generation

- Generators can lose synchronization with the power system

### Operate The Grid For Any Single Element Loss (N-1)(RTCA)



89

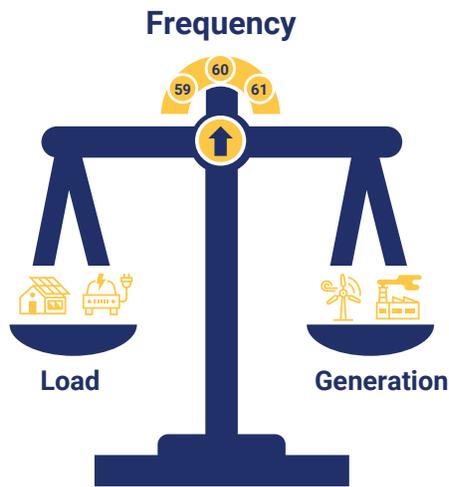
## System Events

- When Equipment Trips (Generators, Transmission Lines, Transformers, Etc.), Power Flows Redistribute
- Higher Loads On The Power System
- Relays Schemes Or Operators Take Action To Prevent Or Mitigate Equipment Overloads
- Field Crews Are Dispatched To Investigate/Repair



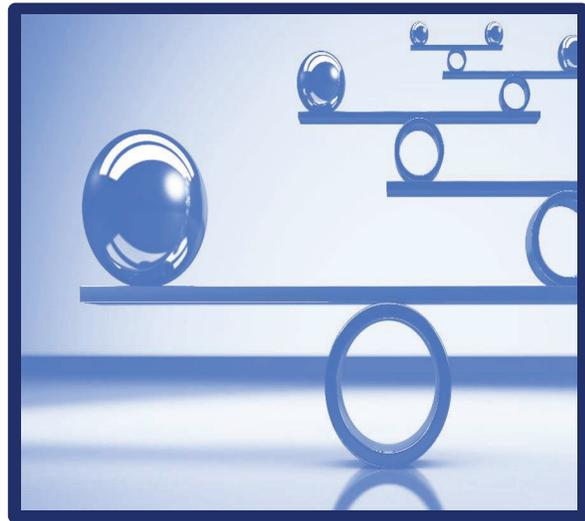
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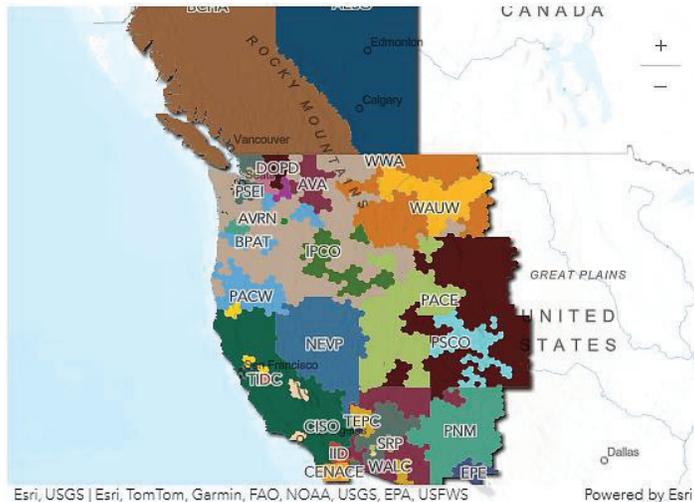
## Balancing Authorities

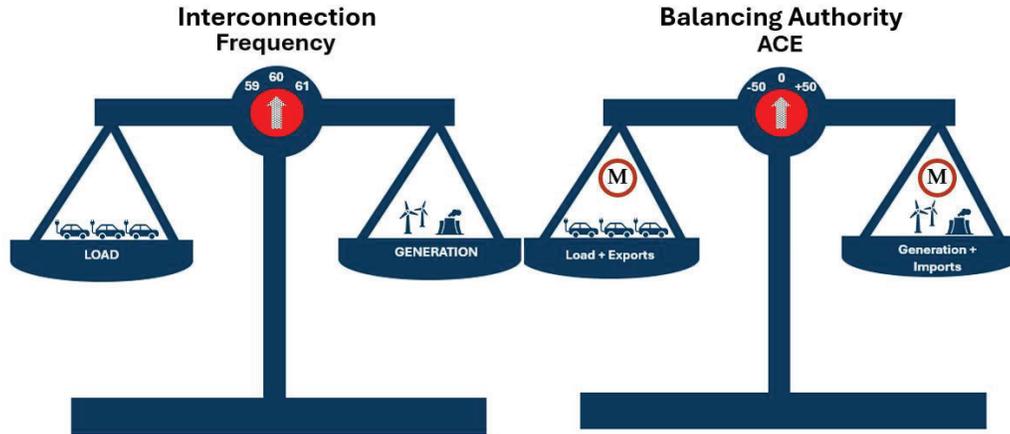
The responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a Balancing Authority Area, and supports interconnection frequency in real-time



## Balancing Authorities

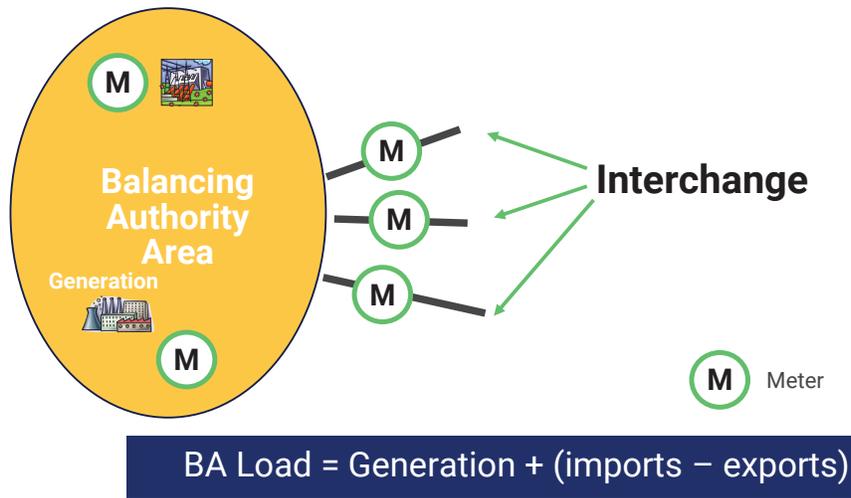
38 Balancing Authorities





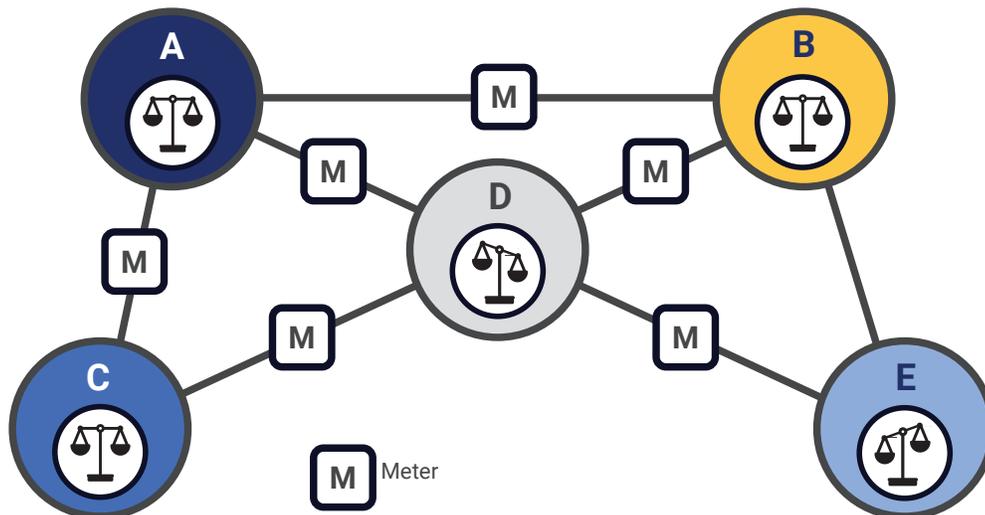
97

## BA Loads and Resources



98

## BA Interconnected Operations



99

## Scenario:

- "East Enders" TV show is about to end
- The British drink a lot of tea
- British grid runs at 50 Hz (the United States runs at 60 Hz)

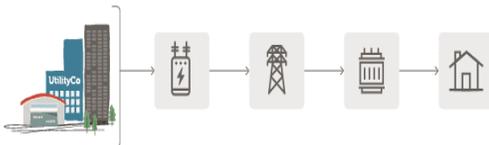


100

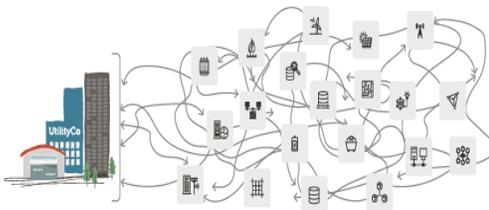


101

## Operational Changes



*The grid was originally designed for centralized power generation and distribution when utilities were the only power producers, demand was captive, and one-way communications were needed. (Courtesy: Oracle Energy and Water)*



*Today's grid must meet the demands of a complex distributed energy generation network in which there are multiple participants often requiring bi-directional communication and control. (Courtesy: Oracle Energy and Water)*

103

## Transmission Service Fair Treatment

### FERC Orders 888/889

- Protects generation competition
- Separation of power marketers and transmission
- Transmission—available to all
- Transmission marketed via an OASIS (Open Access Same-time Information System)

104

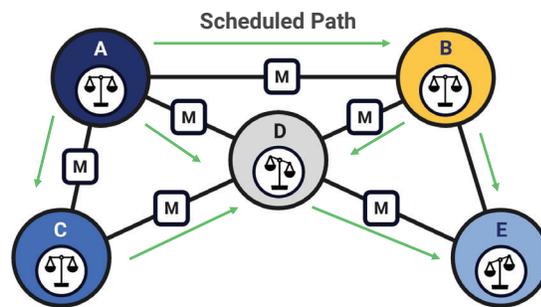
## How Do We Schedule Power?

Area A schedules 100 MW to Area E

Area A generates 100 MW more than load

Area E generates 100 MW less than load

How does the power flow?  
On all available paths

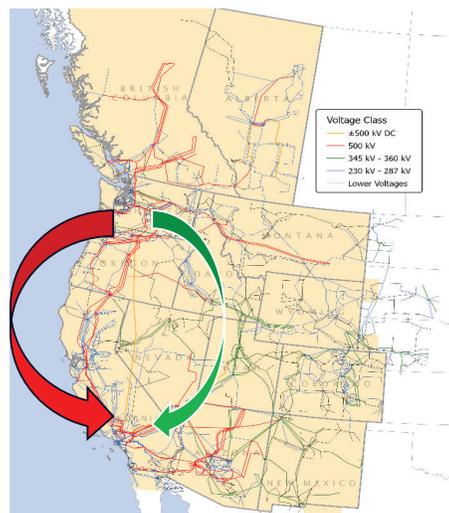


Scheduled flow - Actual flow
=
Unscheduled flow or Loop Flow

105

## Unscheduled (Loop) Flow

- **Example:**
  - 100 MW Scheduled from the Pacific Northwest to Southern California
  - Based on the transmission system configuration and impedance, ~90 MW flows on the 500 kV system along the west coast to Southern California
  - ~10MW flows around the east side of the Western Interconnection to Southern California
  - This ~10MW is unscheduled or loop flow that is clockwise



106

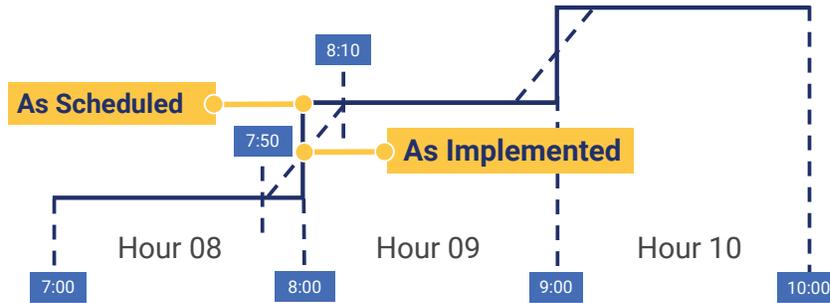
## Electronic Tagging (e-Tag)

- Identifies each transaction
- Identifies all parties and transmission arrangements
- Facilitates timely schedule cuts if problems arise

E-Tag Display ID # PALG-CRA_EX1M_W01_EXT-BA											
Tag Information						Contact Information					
GCA	PSE	Tag Code	LCA			PSE Code	External Marketing				
PALG-CRA	A	W01	EXT-BA			PSE Contact	Jane Rossini				
Start Date	11/5/2007	14:00				PSE Phone	(415) 555-1212				
Stop Date	11/5/2007	14:00				Gen Contact	PALCO Generation Desk				
Time Zone	NFS					Gen Phone	(760) 605-1724				
Connection Type	Normal					Load Contact	External Balancing Auth				
						Load Phone	(415) 655-1712				
Requests											
Request	Type	Time	Status								
Creation	Current Tag	11/5/2007 4:00	Requested								
Market Path											
PSE	Product	Contract	Block/Gen/Value								
PALG-CRA	Generation										
PALG	Transmission										
EXT-BA	Transmission										
EXT-BA	Load										
Physical Path											
Area	TP	PSE	FOR	POD	Sch. Entities	Contract					
B		PALG-CRA	PALCO-Generation								
	PALG	PALG-CRA	C	D	PAL-BA						
EXT-BA	EXT-BA	EXT-BA	E	F	EXT-BA						
	G	EXT-BA	H	I	EXT-BA						
EXT-BA	EXT-BA	EXT-BA	J	K	EXT-BA						
EXT-BA	EXT-BA	External-BA			EXT-BA						
EXT-BA	EXT-BA	External-BA			EXT-BA						
Energy and Transmission Profiles											
Name	Type	Start	Stop	MW	Trans	OASIS #					
PALG-CRA	GEN	11/5/2007 14:00	11/5/2007 14:00	15	15	L					
PALG	TP	11/5/2007 14:00	11/5/2007 14:00	15	15	M					
EXT-BA	TP	11/5/2007 14:00	11/5/2007 14:00	15	15	N					
EXT-BA	TP	11/5/2007 14:00	11/5/2007 14:00	15	15	10036					
Transmission Allocation											
TP	Owner	Product	OASIS								
PALG	PALG	O	17394								
EXT-BA (1)	EXT-BA	P	10021								
EXT-BA (2)	EXT-BA	D	10023								
EXT-BA (3)	EXT-BA	N	10024								
Loss Accounting											
TP	Start Time	Stop Time	Type	Contract Number	Tag ID						
PALG	11/5/2007 14:00	11/5/2007 14:00	Financial								

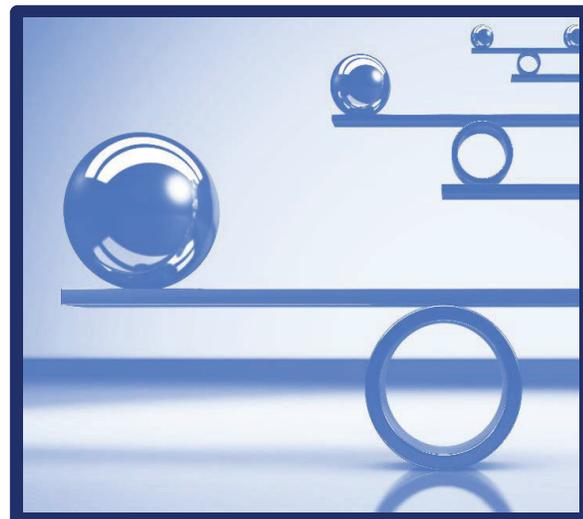
# Power Scheduling

In real time, hourly schedule changes are **ramped** to smooth out abrupt changes



# Balancing Authorities

The responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a Balancing Authority Area, and supports interconnection frequency in real-time

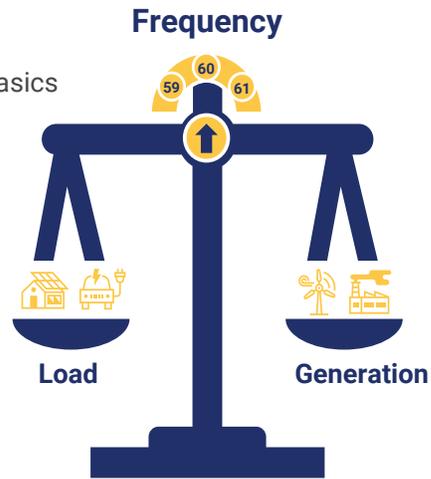


## Load and Generation Balancing

- Automatic Generation Control (AGC) basics

## Frequency Response

- Operating reserves



110

## Automatic Generation Control (AGC)

### Monitors Generation/Load Balance Using Area Control Error (ACE)

- Generation must equal load for good control of frequency

### Adjusts Power Output Of Generators

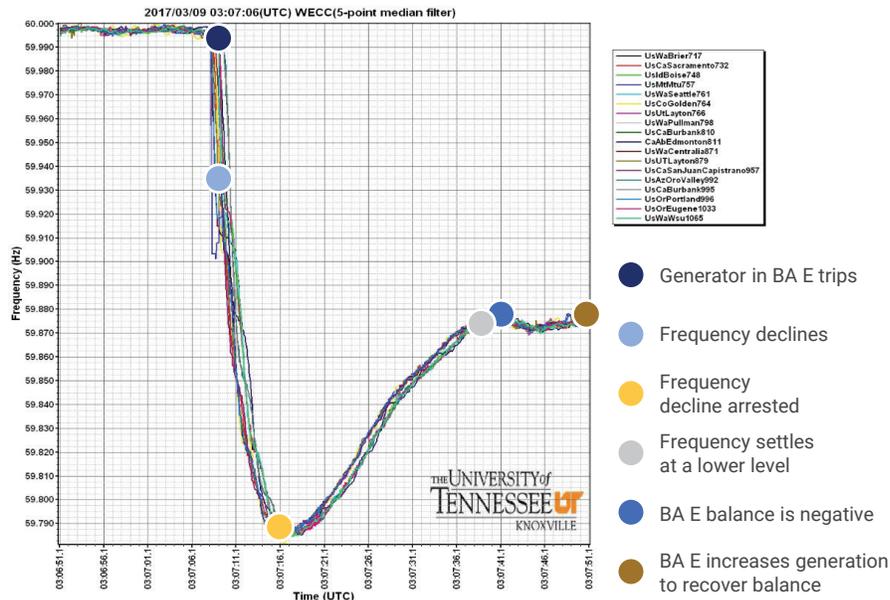
- Short term balance = *"load-frequency regulation"*

### Ramps Generation And Load Schedules

- Longer term balance = *"load following"*

Can Perform Economic Dispatch By Selecting From A Combination Of Generating Units To Minimize Costs

111



112

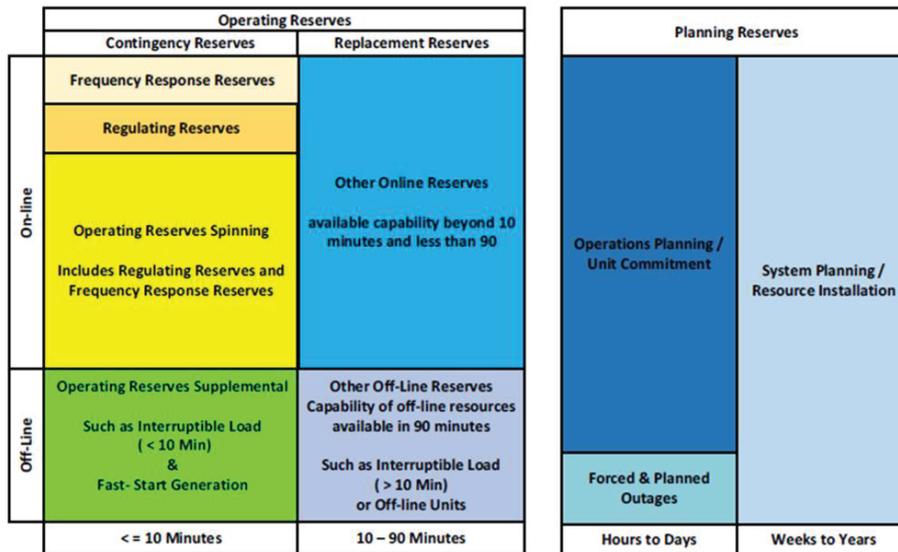
That capability above firm system demand required to provide for regulation, load forecasting error, equipment forced and scheduled outages and local area protection

It consists of spinning and non-spinning reserve

Extra generating capacity needs to be readily available to—

- Replace lost generation or imports
  - Most Severe Single Contingency (MSSC)
- Meet the Disturbance Control Standard (DCS)
  - Recover ACE within 15 minutes

## Operating Reserves



## Reserves

Regulating Reserves	Contingency Reserves
<p>An amount of reserve responsive to Automatic Generation Control, which is sufficient to provide normal regulating margin.</p>	<p>The provision of capacity that may be deployed by the Balancing Authority to respond to a Balancing Contingency Event and other contingency requirements (such as Energy Emergency Alerts as specified in the associated EOP standard).</p>

- A group whose members consist of two or more balancing authorities that collectively maintain, allocate, and supply operating reserves required for each Balancing Authority's use in recovering from contingencies within the group.
- Western Power Pool (formerly Northwest Power Pool)



## Operator and Automatic Responses

**When frequency deviates from 60 Hz  
AGC Causes Generators to Respond**

### Operator Action

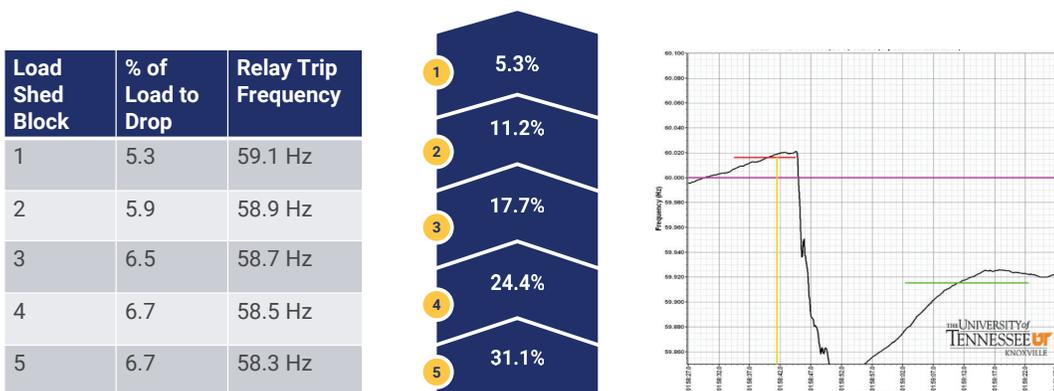
- Routine generation changes
- Interruptible load curtailments
- Manual load shedding (coordinated throughout WECC)

### Automatic Relay Action

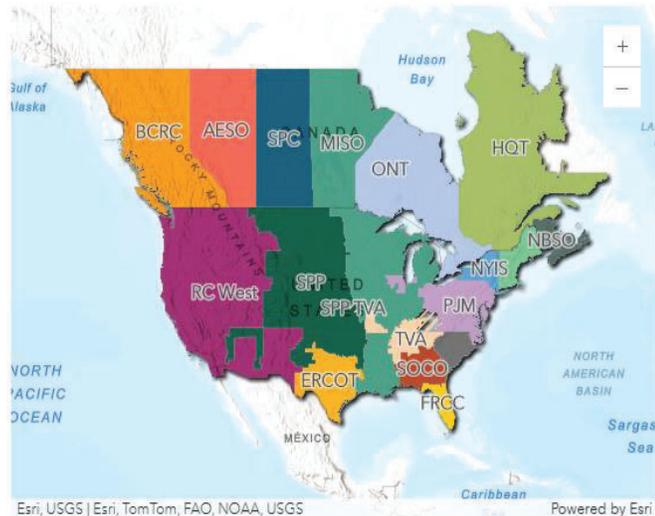
- Underfrequency load shedding – UFLS
- Over-frequency load restoration

## WECC Off-Nominal Frequency Load Shedding Plan

When frequency falls, UFLS helps frequency recover by dropping pre-planned blocks of load throughout the interconnection



Entity with the highest level of authority who is responsible for the reliable operation of the bulk electric system, including the authority to prevent or mitigate emergency operating situations in next-day analysis and real-time operations



119

## Reliability Coordinators

Four Reliability Coordinators



120

## Reliability Coordinators

- Monitor The Real-time RC Area
- Perform RTCA
  - Coordinate/direct actions to be taken
- Notification To RC Area And Other RCs
- Coordinate Planned Outages
- Coordinate System Restoration
- Issue Energy Emergency Alerts
  - EEA 3, Load Shed imminent or in progress

121



### [www.wecc.org](http://www.wecc.org)

The place to start for anything WECC related.



### [WECC Weekly Email Update](#)

Subscribe to receive WECC and ERO Enterprise news.



### [Reliability in the West Discussion Series](#)

Stay current on the most pressing issues in the interconnection.



### [Reliability & Security Workshop](#)

Biannual workshop with robust, relevant content promoting the reliability and security of the Western Interconnection.



### [Reliability & Security Oversight Update](#)

Monthly updates and with a focus on oversight topics.



### [Grid Fundamentals](#)

Comprehensive explanation of how the electric power system works, how it is managed, and why.



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<Limited-Disclosure>

**Grid Fundamentals**

**WECC**

# References

**CREDC**  
CYBER RESILIENT ENERGY DELIVERY CONSORTIUM Education

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## The Power Grid

**Description:**

The power grid is the system of producers and consumers of electricity. It includes power generators, the users of electricity, switches that control the electricity, and the system of substations, power lines, and transformers that deliver the electricity. A community might have a generator to provide its power. The generator may be able to vary its production as the usage of the customers changes, but there may be times when the demand for energy is too great for the generator. Then the community buys electricity from another source. At other times, the generator may be making more electricity than the community is using, so it wants to sell it.

The diagram illustrates a power grid with the following components and capacities:

- External System 1: 550 MW
- Substation 1: 300 MW
- Commercetown: 300 MW
- Substation 2: 840 MW
- Substation 5: 290 MW
- Residenceburg: 500 MW
- Substation 3: 500 MW
- Hydroelectric: 1000 MW
- Natural Gas: 200 MW
- Substation 6: 190 MW
- External System 2: 500 MW
- Substation 4: 660 MW
- Coal: 600 MW
- Industryville: 100 MW
- Nuclear: Offline
- Wind Farm: 199 MW



<https://credc.mste.illinois.edu/applet/pg>

# The Power Grid (2)

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## **All Power Grid components operate together as one system:**

- Generation – Coal, Hydro, Natural Gas, Nuclear, Solar, Wind, Other
- Transmission – Lines, Substations
- Loads – Residential, Industrial, Commerce
- External Neighboring Entities (Balancing Authorities, Transmission Operators)

# The Power Grid – Grid Status

---

## Status:

- Generation = 1,000 MW (Hydro), 200 MW (Wind), 0 MW (Nuclear), 600 MW (Coal), 200 MW (Natural Gas) = 2,000 MW Total
- Load = 500 MW (Res), 100 MW (Industry), 300 MW (Comm) = 900 MW Total
- Interchange = 549 MW + 549 MW = 1100 MW
- Generation MW + Interchange MW = Load MW
- Balanced System! (60 Hz)

# The Power Grid – Scenario 1 – Adding Generation

---

- First press the "Reset System"
- Then, close the "blue switch" to the left of the Nuclear Power Plant (900 MW)
- **What happens to the grid?**
  - Additional generation (900 MW) added
  - If the other resource outputs don't change, and the load remains the same, what changes?

# The Power Grid – Scenario 2 – Changing Loads

- First press the "Reset System"
- Then, increase each of the three loads by the following:
  - Residenceburg to 1,800 MW
  - Industryville to 400 MW
  - Commerceton to 900 MW
- What happens to the grid?
  - Hints: Change in "arrow colors" and External Systems
  - Close the "blue switch" to the left of the Nuclear Power Plant (900 MW)
    - Did any "arrow colors" change? If not, why not?
    - Did the flows change with the External Systems?

# The Power Grid – Scenario 3

---

- First press the "Reset System"
- Then, open the "blue switch" to the External System 1 and the External System 2
- **What happens to the grid?**
  - Why did this happen?
  - "Reset System" again, and look at the flows to both External Systems
  - What action would possibly mitigate this?

# The Power Grid – Homework

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- **Challenges:**
  - On your own, work through Challenges 2–5 for discussion tomorrow morning
  - Have fun!

# Video Links

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## Day 1

- [New York Times 2003 Blackout Video](#)
- [Automatic Governor Control Fly Ball Video](#)
- [Natural Gas Fueled Combustion Turbine Combined Cycle Generator](#)
- [Energy 101: Photovoltaic Solar](#)
- [Disconnect Switches in Action](#)
- [Electric Fence Video](#) (Facebook link as original is no longer on YouTube)
- [Tucson Electric Power Repairing Energized Lines](#)
- [Chief Joe Brake](#) (From Bonneville Power Administration's Facebook Page)

## Day 2

- [Basics of Essential Reliability Services Videos](#) (3 videos)
- [Video of National Grid \(UK\) Responds to a million kettles with operations](#)

# Abbreviations, Definitions, & Information (1)

---

- [U.S. Energy Information Administration \(EIA\) – Glossary](#)
- [NERC Glossary of Terms](#)
- [NERC BES Definition](#)
- [NERC BPS BES FAQ](#)
- [NERC Reliability Functional Model – Definitions and Functional Entities](#)
- [WECC Study Program Glossary of Terms](#)
- [California ISO Glossary](#)
- [Southwest Power Pool Glossary](#)

# Abbreviations, Definitions, & Information (2)

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- [WECC's Risk Management Program](#)
- [NERC's Risk Framework](#)
- [NERC Essential Reliability Services](#)
- [Keeping the Lights On: Essential Reliability Services | Department of Energy](#)
- [UTK FNET Server Web Display](#)
- [NERC – The Basics of Essential Reliability Services on Vimeo](#)
- [NERC History book](#)
- [Energy Policy Act of 2025](#)

# Abbreviations, Definitions, & Information (3)

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- [An Introductory Guide to Electricity Markets regulated by the Federal Energy Regulatory Commission \(FERC\)](#)
- [Western Energy Markets Explainer | Federal Energy Regulatory Commission](#)
- [NERC 2025 State of Reliability – Technical Assessment](#)



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