EBA Primer Series: Electric Industry Technology for Lawyers

Thursday and Friday, February 15-16, 2018

Location: Western Area Power Administration Headquarters, 1667 Cole Boulevard, Building 19, Suite 152 Golden, CO

About the EBA Primer Series:

One of the goals of the Energy Bar Association’s Strategic Plan is to promote excellence in the practice of energy law by enhancing opportunities for educational programming. To further this goal, EBA has established a “primer program,” focused on teaching core regulatory and legal concepts and basic industry fundamentals that every energy law practitioner must understand. The overall goal of this course is to provide attorneys new to the oil and refined products pipeline industry a foundational understanding of the industry and how it is organized and regulated, so they are better equipped to assist clients in this industry.

Location: Additional details: here is a PDF of the map and directions. URL for the address https://goo.gl/maps/a2ZaC96F8Jm. Parking is free in this area.

Agenda

Thursday, February 15

Noon – 1:00 pm: Lunch and Networking – boxed lunch is provided

1:00 pm: Introduction to Primer

I. Introductory Concepts: In this segment of the Primer, participants will learn the basic terminology and concepts for understanding the technology behind the electric grid, such as the basic tools for measuring electricity, the difference between capacity and energy, the difference between real and reactive power, and the difference between direct and alternating current. Students will gain an understanding of how today’s electrical grid is configured – and why.

A. Watts, Volts, Amps, Hz
B. kW, kWh, MW, MWh
C. DC, AC
D. Reactive Power
E. Diagram of the Electric Grid

2:15 pm - 4:00pm:

II. Distribution: This segment of the program will focus on the equipment that is used in the delivery of electricity to retail consumers. Students will gain an understanding of the difference between network and radial systems, where and why electric meters are located, operational issues faced by utility operators, how key distribution equipment such as
protection systems and transformers work, and what happens in a control room – the place where operation of the electric grid all comes together.

A. Definition

B. Network, Radial
C. Meters
D. Operational Issues
   1. Safety
      a. Short-circuit current
   2. Reliability
   3. Power quality
      a. Voltage control (e.g., capacitors)
E. Protection Systems
F. Transformers
G. Down-line Automation
H. Distribution SCADA (Supervisory Control and Data Acquisition), Control Room Operations
I. Bi-directional Distribution Systems

4:00 pm – 5:30 pm:

III. Transmission: This part of the program will focus on the equipment that is used to deliver electricity from generators to distribution systems and between distribution systems. Students will gain an understanding of the key components of the transmission system such as towers, insulators and conductors, how transmission systems are designed (including concepts such as stability and thermal limits), and operational issues confronted by transmission operators (including loop flows and vegetation management).

5:30 pm - Networking Reception (included in Primer registration fee)

7:30 pm - Dinner on your own

Friday, February 16 - 8:00 am – 12:30 pm

7:30 am – 8:00 am: Continental Breakfast

8:00 am – 9:30 am:

IV. Generation: This segment of the program will address the basic technological concepts underlying electric generation, followed by an in-depth review of the various types of generating technologies. Students will gain an understanding of the basics of generation, including the difference between baseload, intermediate, peak and intermittent generation; heat rate; blackstart generators; and station power. Our instructors will then discuss different types of generation – coal, natural gas, and nuclear – and the environmental controls that are used in power plants using those fuels. The session will wrap up with a discussion of renewable generation (hydropower, wind, solar, and biomass).

A. General
   1. Baseload, intermediate, peaking, intermittent
2. Heat rate
3. Automatic Generation Control (AGC)
4. Reactive controls
5. Inertia
6. Blackstart
7. Station power

B. Coal
1. Different boiler designs and efficiency options up to ultra-supercritical
2. Differences in coal
3. Coal gasification
4. Cycling issues

C. Gas
1. Reciprocating internal combustion engine (RICE), aeroderivative turbines
2. Simple, combined cycle

D. Nuclear
1. Basic designs
2. Fuel supply
3. Spent fuel storage
4. Containment technology

E. Environmental Controls
1. Selective Catalytic Reduction (SCR) and Non-Selective Catalytic Reduction (NSCR)
2. Bag house
3. Mercury controls
4. Solid waste management
5. Liquid waste management
6. Carbon Capture and Storage (CCS)

F. Renewables
1. Hydro
   a. Licensed, federal
   b. Impoundments, run-of-river, pumped storage
2. Wind
3. Solar (photovoltaic, concentrated)
4. Biomass
   a. Landfill gas
   b. Municipal waste
   c. Wood waste
   d. Dedicated fuel (e.g., switchgrass)
   e. Animal digesters
   f. Poultry waste

Coffee Break

V. Distributed Energy Resources (DER): This segment of the seminar will address new technologies that perform a power supply function. The session will cover the basics of distributed generation (DG) technologies, including combined heat and power and small renewable generators and how they are integrated with the electric grid. The session will also address energy storage, energy efficiency, and demand response, including how they are dispatched by grid operators. Our instructors also will cover emerging issues such as the impact of the Internet of Things and electric vehicles.
A. Distributed Generation (DG) Technologies
   1. RICE units
   2. Combined heat and power (CHP) (a/k/a cogeneration)
   3. Solar, distributed wind, small hydro
B. Storage
   1. Thermal, mechanical, battery (different chemistries)
C. Energy Efficiency (EE)
D. Demand Response (DR) (devices and control systems)
E. Internet of Things (IOT)
F. Electric Vehicles (EVs)
G. Integration Issues
   1. Standards
   2. Inverter technology
   3. Potential impact on distribution grid
   4. Potential impact on transmission
H. Dispatch of DER
   1. Generally
   2. DER and natural / man-made disasters

12:30 pm Wrap up and Adjourn

**EBA wishes to thank**

**Western Area Power Administration**

*For hosting and teaching this Primer*

**Optional Post-Primer Tour:**

Currently, we are working on an optional post-primer tour of the Xcel dispatch center the afternoon of Friday Feb 16; You are responsible for your own transportation to the tour which is easily accessible by taxi and Uber. You must respond your interest in the tour, to Lisa Levine at llevine@eba-net.org.
About the Trainers

THOMAS RIAL FOX II, EPTC INSTRUCTOR

Thomas received his certification as a training professional from Texas A & M, and holds current certification as a NERC reliability coordinator. He brings more than 13 years' experience in the utility industry to EPTC, following a 20-year career as a machinist mate in the US Naval Nuclear Propulsion Program.

His experience includes providing technical and engineering support for construction and implementation of NERC-certified operations control centers, wind farm interconnections, generation, transmission and distribution operations, DC Ties, maintenance and safety procedures. Thomas has also developed compliance process procedures for analytical study completion, assessment and audit support.

As a trainer, Thomas has conducted classes in instructor training, E-learning, learning management systems and presentation creation and maintenance. He has also presented courses on compliance, hydro units, gas and oil fired boilers, DC tie maintenance, operation and upgrades, qualified scheduling entity, transmission and distribution control and dispatch.

Prior to joining the WAPA EPTC, Thomas served as the transmission operations specialist at Cross Texas Transmission and Sharyland Utilities, operations training supervisor and senior operator at the Garland Power & Light Operations Center and Spencer Generation Station.

KYLE CONROY - EPTC MANAGER

Kyle has more than 35 years’ experience in the electrical utility industry, starting as a U.S. Air Force Electrical Power Lineman. He became a USAF Instructor in the Electrical Power Lineman Training program completing all phases of USAF instructor training and development curriculum and achieved recognition as a master instructor. Kyle simultaneously completed the requirements for a Bachelor of Science degree in Occupational Education as well as those for a Technical Training Teaching Practicum.

His post-military experience includes working with Southern Companies as a power linemen, distribution operator and engineering assistant at Gulf Power, and with Savannah Power & Light as a transmission system supervisor. Kyle moved to Colorado in 2002 and has worked as a senior system operator and power operations specialist at Tri-State Generation and Transmission Association. WAPA hired Kyle as a power dispatcher/trainer in its Rocky Mountain regional office in 2014 before bringing him into the EPTC three years later.

His technical, operational and training experience also include completion of Master of Education degree in Human Resource Studies with a focus on Adult Education and Training.

JOSEPH LIBERATORE

Joe is currently on a Detail at the Electric Power Training Center (EPTC) in Golden CO. His previous six years were performing the duties of field engineer that included commissioning greenfield switchyards, transformer replacements, RTU design and installation, substation upgrades, protective relay replacements and project leadership responsibilities with the Western...
Area Power Administration (WAPA) in Loveland, CO. Prior to his field experiences, he spent a combined seven years in both planning and operations support at WAPA where his roles include transmission planning and real-time system reliability. He graduated with a B.S. in Electrical Engineering and a M.S. in Systems Engineering from Colorado State University, Ft. Collins CO. Prior to his formal education as a non-traditional student, Mr. Liberatore spent 15 years in construction, primarily in the concrete industry.

EROL CHARTAN

Erol Chartan conducts research and development of power system simulations and wind power forecasts developing models in both spaces and performing analysis mainly to provide insight into the integration of renewables. Prior to joining NREL, he worked as a power systems modeling consultant in London and previously in the Electricity National Control Room for the Great British transmission network operator.”

Continuing Legal Education Credits (CLE)

Pending: MCLE accreditation has been submitted for VA, NY, CO. For questions email llevine@eba-net.org
Welcome
Energy Bar Association
Golden, CO
Feb. 15-16, 2018

Thank You to Our Host and Instructors from WAPA

Electric Power Training Center
Golden, Colo.
https://www.wapa.gov/EPTC/Pages/eptc.aspx

Providing the highest quality power system operations training for audiences of all levels, with fully operational power system simulators for student experiential learning.
Disclaimer

The views expressed herein are the authors', and do not necessarily reflect the views of WAPA or WAPA staff.

EBA Primer Series
Electric Industry Technology for Lawyers

Conventional Generation

Thomas Fox
Western Area Power Administration

Energy Bar Association
Golden, CO
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Agenda

- Types of Generation
  - Baseload, intermediate, peaking
  - Heat rate
  - Automatic Generation Control (AGC)
  - Reactive controls
  - Inertia
  - Blackstart
  - Station Power
- Natural Gas
- Coal
- Nuclear
- Environmental Controls

Objectives

- List sources of energy (chemical, nuclear, hydro, kinetic, geothermal, etc.) used by the prime mover of a generating unit
- List advantages / disadvantages of different energy sources (cost, availability, environment)
- Describe process / systems for energy conversion (combustion, fission, electric generator, solid state inverters) and their relative efficiency
- Explain the meaning and typical applications of cogeneration
What Are the Primary Energy Sources?

- **solar energy** . . . sunlight
- **biomass** . . . plants
- **water power** . . . flowing water
- **fossil fuel energy** . . . coal, natural gas, oil
- **nuclear energy** . . . uranium, plutonium, hydrogen
- **geothermal energy** . . . heat from inside the Earth
- **tidal energy** . . . gravity of the Moon and Sun affects the oceans
- **wind energy** . . . moving air caused by the sun heating the atmosphere
Energy Equivalents

- Fuels have different energy content
- Some sources produce the same amount of electricity from less fuel

Power Grid
Voltage Levels from Power Plant to Consumer

U.S. Electric Generating Capacity Increase in 2016 Was Largest Net Change Since 2011

Source: U.S. Energy Information Administration, Electric Power Annual and Preliminary Monthly Electric Generator Inventory
Electrical energy is generally referred to as:

- Base Load
- Intermediate Load
- Peak Demand

Base load is usually the least expensive to produce, and peak load the most expensive.

- Intermediate load is that load that changes due to weather, human activity, seasonal, etc.
- Intermittent load is load that cycles, such as a steel mill, or may exceed a level specified by the market.
• Four characteristic curves describe the efficiency and resulting costs associated with operating a particular generating unit
• These four curves plot:
  ▪ Fuel Cost
  ▪ Heat Rate
  ▪ Input-Output
  ▪ Incremental Cost

Generator Economic Curves (cont’d)

Fuel Cost Curve
The fuel cost curve specifies the cost of fuel used per hour by the generating unit as a function of the unit’s MW output. This is a monotonically increasing convex function.

Input-Output Curve
The input-output curve is derived simply from the heat-rate curve by multiplying it by the MW output of the unit. This yields a curve showing the amount of heat input energy required per hour as a function of the generator’s output.
Heat-Rate Curve

The heat rate curve plots the heat energy required per MWh of generated electrical output for the generator as a function of the generator’s MW output. Thus, the heat rate curve indicates the efficiency of the unit over its operating range. Generally, units are least efficient at the minimum and maximum portions of their MW output capability and most efficient somewhere in the middle of their operating range. The vertical axis is plotted in MBtu/MWh and the horizontal axis is plotted in MW. You may interpret the heat rate for a generator producing X MW as follows: the heat rate indicates the amount of heat input energy per MWh of generation required to produce X MW of power. The lower this number, the less input energy is required to produce each MWH of electricity.

Incremental Cost Curve

By multiplying the input-output curve by the cost of the fuel in $/MBtu, one obtains the cost curve for the unit in $/hr. By taking the derivative of the cost curve, one obtains the incremental cost curve, which indicates the marginal cost of the unit: the cost of producing one more MW of power at that unit.
• Generation (electrical energy) cost is a function of:
  - Plant Cost (construction, financing, insurance, administration, personnel, etc.)
  - Fuel Cost
  - Operation and Maintenance Cost
  - Transmission and Distribution Costs

• When dispatching certain generation assets, a utility must consider the cost energy produced from the device and its duration of operation
• Some plants need long lead times to start and stop
• Others have high capital costs or operation and fuel costs
• A typical large thermal plant may take days to start and stop and 7-10 years to construct (longer to get approvals)
Heat rate is one measure of the efficiency of a generator or power plant that converts a fuel into heat and into electricity.

The heat rate is the amount of energy used by an electrical generator or power plant to generate one kilowatt-hour (kWh) of electricity.

The U.S. Energy Information Administration (EIA) expresses heat rates in British thermal units (Btu) per net kWh generated.

Net generation is the amount of electricity a power plant (or generator) supplies to the power transmission line connected to the power plant.

- Gross generation accounts for all the electricity that the power plant consumes to operate the generator(s) and other equipment, such as fuel feeding systems, boiler water pumps, cooling equipment, and pollution control devices.
Heat Rate (cont’d)

• Measure of efficiency of a unit in converting heat energy to electrical energy
  ▪ Ratio of heat supplied by fuel (MBtu) to MWh of electrical energy delivered by a unit
  ▪ MBtu stands for one million Btus, which can also be expressed as one decatherm
  ▪ Btu stands for British Thermal Units
• As heat rate increases, efficiency decreases

Heat Rate (cont’d)

• To express the efficiency of a generator or power plant as a percentage, divide the equivalent Btu content of a kWh of electricity (3,412 Btu) by the heat rate
• For example:
  ▪ If the heat rate is 10,500 Btu, the efficiency is 33%
  ▪ If the heat rate is 7,500 Btu, the efficiency is 45%
Heat Rate Example

Heat Rate = \frac{MBTU}{MWh} = \frac{Heat Input (MBTU)}{MW Output (MWh)}

EXAMPLE:

Heat Rate = \frac{312 \text{ MBTU/hr}}{30 \text{ MW}} = 10.4 \text{ MBTU/MWh}

Diagram:

- Most efficient generation level

\( \frac{mWh}{mBTU} \)

\( P_{\text{gen}} \)
It is important to understand that the lower the heat rate, the more efficient the unit.

The above use of the term “heat rate” is sometimes also called the “average heat rate”

This is because we get it by dividing absolute values of fuel input rate by absolute values of electric output power

For example, if you buy an apple at $50 and a second one at $10, the average cost of apples after buying the first apple is $50/apple, but after buying the second apple is $(50+10)/2=$30/apple
Incremental Heat Rate (IHR)

- IHR is critical to economic operation and dispatching of the power system generation
- IHR is the change in the unit’s heat input (energy) required for a given change in the generation output

Incremental Heat Rate (IHR) (cont’d)

- Incremental cost for a unit at a given level of generation is the cost per MW to produce the next increment of power output
- Is calculated by taking the product of the incremental heat rate and the fuel cost
Incremental Heat Rate (IHR) (cont’d)

- Increment of heat input = 392 MBTU/hr - 312 MBTU/hr = 80 MBTU/hr
- Increment of power output = 40 MW - 30 MW = 10 MW

\[
\text{IHR} = \frac{\text{Increment of heat input (MBTU)}}{\text{Increment of Power Output (MWhr)}}
\]

\[
\text{IHR} = \frac{80 \text{ MBTU/hr}}{10 \text{ MW}} = 8.0 \text{ MBTU/MWhr}
\]

Incremental Heat Rate (IHR) (cont’d)

<table>
<thead>
<tr>
<th>POWER OUTPUT (MW)</th>
<th>IHR (MBTU/MWhr)</th>
<th>INC. COST ($/MWhr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>7.6</td>
<td>(7.6 \times 2.3) = 17.5</td>
</tr>
<tr>
<td>30</td>
<td>7.6</td>
<td>(7.6 \times 2.3) = 17.5</td>
</tr>
<tr>
<td>40</td>
<td>8.0</td>
<td>(8.0 \times 2.3) = 18.4</td>
</tr>
<tr>
<td>50</td>
<td>8.4</td>
<td>(8.4 \times 2.3) = 19.3</td>
</tr>
<tr>
<td>60</td>
<td>8.8</td>
<td>(8.8 \times 2.3) = 20.2</td>
</tr>
<tr>
<td>70</td>
<td>9.2</td>
<td>(9.2 \times 2.3) = 21.2</td>
</tr>
<tr>
<td>80</td>
<td>10.2</td>
<td>(10.2 \times 2.3) = 23.5</td>
</tr>
<tr>
<td>90</td>
<td>11.6</td>
<td>(11.6 \times 2.3) = 26.7</td>
</tr>
<tr>
<td>100</td>
<td>12.7</td>
<td>(12.7 \times 2.3) = 29.2</td>
</tr>
</tbody>
</table>

Inc. Cost = IHR \times Fuel Cost

$/\text{MWhr} = \text{MBTU/MWhr} \times \$/\text{MBTU}

Fuel Cost = $2.30 / MBTU
Incremental Heat Rate (IHR) (cont’d)

- **What is a Governor?**
- **A device for controlling the speed of a prime mover**
  - Mechanical-Hydraulic
  - Electrohydraulic (Analog or Digital)
- **PRIMARY**
  - Individual Unit Governors
- **SECONDARY**
  - AGC (Automatic Generation Control)
Automatic Generation Control (cont’d)

- In an electric power system, automatic generation control (AGC) is a system for adjusting the power output of multiple generators at different power plants, in response to changes in the load
- Since a power grid requires that generation and load closely balance moment by moment, frequent adjustments to the output of generators are necessary

Automatic Generation Control (cont’d)

- The balance can be judged by measuring the system frequency; if it is increasing, more power is being generated than used, which causes all the machines in the system to accelerate
- If the system frequency is decreasing, more load is on the system than the instantaneous generation can provide, which causes all generators to slow down
Reactive Controls

- Reactive Controls
  - Voltage Support
  - Vars
  - Planning and Modeling
- Reactive support and control involves numerous functional entities
  - However, bulk reactive power cannot be transmitted as far as real power
- Therefore, the functional entities which need to plan, operate, and control reactive power are more localized and close coordination is required

Reactive Controls (cont’d)

- The physical laws of Reactive Energy Conservation cannot be broken
- Each of the four separate Interconnections within NERC operates every moment of every day at unity Power Factor
- In other words, Interconnection total customer reactive demand plus total system reactive losses must equal reactive power supply
- Reactive power cannot be imported over Interconnection asynchronous DC tie lines
• The Interconnection total production of reactive power must equal customer demand plus losses
• If a production shortage occurs, voltage will immediately decline until customer demand plus losses decreases to match supply
• Small production shortages will result in small degradation of grid voltage
• Larger production shortages lead to severe low voltage or collapse
• Severe low customer voltage may also result in motor protection operation and resulting equipment outages due to high motor currents caused by low voltage

• Maintained by:
  ▪ Generation Voltage Profiles
  ▪ Capacitors
  ▪ Reactors
  ▪ Transformer Tap Changers
• In power transmission, since loads such as motors are inductive, reactive power is present in the system.

• Since reactive power does not do any real work, the extra current supplied to provide the reactive power means greater line losses and higher thermal limits for equipment.

Reactive Controls (cont’d)

• Managing the reactive power flow in addition to real power flow becomes a very important task for operators to ensure voltage stability throughout the system.

• In general terms, decreasing a supply of reactive power to the system causes voltage to fall while increasing it causes voltage to rise.

• A voltage collapse occurs when the system serves a transient load that has a higher reactive power demand than the system can supply.
• Reactive loads such as inductors and capacitors dissipate zero power, yet the fact that they drop voltage and draw current gives the deceptive impression that they actually do dissipate power.
• This “phantom power” is called reactive power, and it is measured in a unit called Volt-Amps-Reactive (VAR), rather than watts.

• The actual amount of power being used, or dissipated, in a circuit is called true power, and it is measured in watts.
• The combination of reactive power and true power is called apparent power, and it is the product of a circuit’s voltage and current.
Inertia

- Inertia is one of the most basic concepts of physics
- Essentially, things that are moving will keep moving unless a force – like friction – causes them to stop
- And, things that are not moving will continue to not move unless a force – like a gust of wind – causes them to move
- All of the spinning mass in the electrical grid (steam turbines, gas turbines, hydro’s, even wind turbines) has the inertia of all that spinning mass
- This inertia of the spinning mass is stored energy, which can be used to help maintain system stability

Black Start

- Black Start is the term for system restoration from a system collapse
  - Sometimes referred to bootstrap
- System restoration without reliance on external systems
- Units can “self-start” without external power sources
  - Then provide power to the system, and support the starting of another unit, “next start”
1. Inlet Section
2. Compressor
3. Combustion System
4. Turbine
5. Exhaust System
6. Exhaust Diffuser

Courtesy of Siemens Westinghouse
Reciprocating Internal Combustion Engines (cont’d)

- Power plants that can be dispatched within minutes are important assets for balancing electric system loads and maintaining grid reliability.
- The generating technology affects the time required for a power plant to startup and reach full load.
- While combined cycle gas turbines can take over 30 minutes to start, combustion engine power plants can start and reach full load in less than 10 minutes – providing flexible, quick-start capability.

Coal

- Coal is a rock that can burn.
- Coal is an energy source.
- Coal is a sedimentary rock.
- Coal is an energy mineral (legally a mineral, scientifically a rock).
- Coal is fossil fuel (because it is derived from fossil plant remains).
- Coal is a solid hydrocarbon (because it consists mostly of carbon, hydrogen, and oxygen; in contrast, oil is a liquid hydrocarbon, and natural gas is a gaseous hydrocarbon).
- Coal and the peat it comes from are part of the carbon cycle.
Coal (cont’d)

[Map of the United States with coal deposits marked]

Coal (cont’d)

[Diagram showing the formation of coal through time, pressure, and heat]

Peat

Lignite (brown coal)

Sub-bituminous

Bituminous

Anthracite

Banded “black” coals
Coal (cont’d)

Coal is classified into four main types, or ranks: anthracite, bituminous, subbituminous, and lignite.

The ranking depends on the types and amounts of carbon the coal contains and on the amount of heat energy the coal can produce.

The rank of a coal deposit is determined by the amount of pressure and heat that acted on the plants over time.
• **Anthracite** contains 86%-97% carbon, and generally has the highest heating value of all ranks of coal
• Anthracite accounted for less than 1% of the coal mined in the United States in 2015
• All of the anthracite mines in the United States are in northeastern Pennsylvania
• Anthracite is mainly used by the metals industry

• **Bituminous** coal contains 45%–86% carbon
• Bituminous coal in the United States is between 100 and 300 million years old
• Bituminous coal is the most abundant rank of coal found in the United States, and it accounted for 45% of total U.S. coal production in 2015
• Bituminous coal is used to generate electricity and is an important fuel and raw material for making iron and steel
• West Virginia, Kentucky, Illinois, Pennsylvania, and Indiana were the five main bituminous coal-producing states in 2015, accounting for 73% of total bituminous production
Coal (cont’d)

- **Subbituminous** coal typically contains 35%-45% carbon, and it has a lower heating value than bituminous coal
- Most subbituminous coal in the United States is at least 100 million years old
- About 47% of total U.S. coal production in 2015 was subbituminous and nearly 90% was produced in Wyoming
  - The Powder River Basin is a geologic region that straddles southeast Montana and northeast Wyoming and is known for its coal and coalbed methane deposits
  - Using a geology-based assessment methodology, the U.S. Geological Survey estimated in-place resources of 1.07 trillion short tons of coal in the Powder River Basin, Wyoming and Montana
  - Of that total, with a maximum stripping ratio of 10:1, recoverable coal was 162 billion tons
  - The estimate of economically recoverable resources was 25 billion tons

Coal (cont’d)

- **Lignite** contains 25%-35% carbon and has the lowest energy content of all coal ranks
- Lignite coal deposits tend to be relatively young and were not subjected to extreme heat or pressure
- Lignite is crumbly and has high moisture content, which contributes to its low heating value
- Lignite accounted for 8% of total U.S. coal production in 2015
- About 90% of total lignite production is mined in Texas and North Dakota in 2015, where it is mostly used to generate electricity
- A facility in North Dakota also converts lignite to synthetic natural gas and pipes it to natural gas consumers in the eastern United States
• Gasification is a partial oxidation process
• The term partial oxidation is a relative term which simply means that less oxygen is used in gasification than would be required for combustion (i.e., burning or complete oxidation) of the same amount of fuel
• Gasification typically uses only 25 to 40 percent of the theoretical oxidant (either pure oxygen or air) to generate enough heat to gasify the remaining unoxidized fuel, producing syngas

Coal (cont’d)

• The major combustible products of gasification are carbon monoxide (CO) and hydrogen (H₂), with only a minor amount of the carbon completely oxidized to carbon dioxide (CO₂) and water
• The heat released by partial oxidation provides most of the energy needed to break up the chemical bonds in the feedstock, to drive the other endothermic gasification reactions, and to increase the temperature of the final gasification products
Steam coal (sometimes called thermal coal) is a grade of coal used in electric power plants to generate steam to create electricity.

Most of the coals mined in the United States are steam coals.

Steam coals for power plants must meet quality and heating characteristics of the boiler design and for the design of pollution-control equipment at a power plant.
Coal (cont’d)

- U.S. nuclear plants are licensed for an initial operating life of 40 years by the Nuclear Regulatory Commission (NRC)
- Owners of nuclear power plants can apply for a license renewal, extending license expiration by 20 years
- The decision to apply for a renewal is based on the economics of the capital investments required to extend the operating lifetime and estimated future revenues
- As of 2016, the NRC had granted license renewals to 84 of the 99 operating reactors in the United States
• Energy given off by matter in the form of tiny fast-moving particles (alpha particles, beta particles, and neutrons) or pulsating electromagnetic rays or waves (gamma rays) emitted from the nuclei of unstable radioactive atoms

• All matter is composed of atoms, which are made up of various parts; the nucleus contains minute particles called protons and neutrons, and the atom’s outer shell contains other particles called electrons

• The nucleus carries a positive electrical charge, while the electrons carry a negative electrical charge

• These forces work toward a strong, stable balance by getting rid of excess atomic energy (radioactivity)

• In that process, unstable radioactive nuclei may emit energy, and this spontaneous emission is called nuclear radiation

• All types of nuclear radiation are also ionizing radiation

Nuclear (cont’d)

• Radiation can be either ionizing or non-ionizing, depending on how it affects matter
  • Non-ionizing radiation includes visible light, heat, radar, microwaves, and radio waves
  • This type of radiation deposits energy in the materials through which it passes, but it does not have sufficient energy to break molecular bonds or remove electrons from atoms
  • By contrast, ionizing radiation (such as x-rays and cosmic rays) is more energetic than non-ionizing radiation
  • Consequently, when ionizing radiation passes through material, it deposits enough energy to break molecular bonds and displace (or remove) electrons from atoms
  • This electron displacement creates two electrically charged particles (ions), which may cause changes in living cells of plants, animals, and people
• Radiation Shielding / Protection:
  • Generally in nuclear industry the radiation shielding has many purposes
  • In nuclear power plants (NPPs), the main purpose is to reduce the radiation exposure to persons and staff in the vicinity of radiation sources
  • In NPPs, the main source of radiation is conclusively the nuclear reactor and its reactor core
  • Nuclear reactors are, in general, powerful sources of entire spectrum of types of ionizing radiation
  • Shielding used for this purpose is called biological shielding
• There are two acceptable storage methods for spent fuel after it is removed from the reactor core:
  • Spent Fuel Pools – Currently, most spent nuclear fuel is safely stored in specially designed pools at individual reactor sites around the country
  • Dry Cask Storage – Licensees may also store spent nuclear fuel in dry cask storage systems at independent spent fuel storage facilities (ISFSIs) at the following sites:
    • At Reactor – Licensees may use dry storage systems when approaching their pool capacity limit
    • Away-From-Reactor – Licensees may use dry storage systems at one of the following locations:
      • Decommissioned Reactor Sites – After terminating reactor operations and removing structures used in reactor operations, the licensee stores spent fuel on-site pending off-site transport to either a site-specific ISFSI that is authorized to receive the spent fuel, or a permanent geologic repository licensed for disposal
      • Consolidated Interim Storage Facility (CISF) – Dry cask storage at an away-from-reactor site pending disposal at a permanent disposal facility
A nuclear chain reaction is more difficult to keep going because many of the neutrons will not hit another uranium atom. As fewer fissions happen, the chain reaction slows down and stops.

A nuclear power plant uses uranium for fuel.

Uranium .....  
- is a dense, heavy metal  
- consists of atoms that hold a lot of energy in their nuclei  
- is found in ordinary rocks and soil around the world.

Uranium ore is mined as rocks like this one.
Most uranium is mined by a process called in situ mining, which means mining "in place." First, a well is drilled, and water and oxygen are injected into the ore deposit. This causes the uranium in the ore to oxidize (rust) and wash out in the water. The water is then pumped back to the surface and the uranium is filtered out. What's left is a dry, yellow powder called yellowcake.

Some uranium is also mined in surface and deep mines.

- Only uranium-235 is fissionable
  - Natural uranium in yellowcake is less than one percent U-235
  - A nuclear power plant needs fuel that is four percent U-235
- Uranium need to be treated to be enriched to increase the percent of U-235

Weapons-grade uranium is enriched to 90% U-235.
Nuclear (cont’d)

UF6 is a solid, gas, and liquid.

Before it can be enriched, yellowcake is converted into uranium hexafluoride (UF6). At room temperature, UF6 changes into solid crystals that look like this:

When the crystals are heated, they become a gas.

Nuclear (cont’d)

Uranium hexafluoride (UF6) is enriched by either gaseous diffusion or gas centrifuge.

Gaseous diffusion pumps UF6 gas through filters. The slightly heavier U-238 doesn’t pass through the membrane as easily as U-235.
The gas centrifuge process is another way to enrich uranium.

This process uses a spinning cylinder, much the way a washer spins water out of wet clothes.

The spinning throws the heavier U-238 atoms toward the outside while the lighter U-235 atoms collect near the center.

Nuclear (cont’d)

- Enriched uranium for a power plant has about 4 percent U-235
- It is made into a ceramic material
- **Formed into small fuel pellets, weighing less than an ounce, but having the energy content of a ton of coal**
- Stacked in rods that are grouped into assemblies
- Sent to nuclear power plants
- The fuel lasts for 3 years
• A containment building, in its most common usage, is a reinforced steel or lead structure enclosing a nuclear reactor
• It is designed, in any emergency, to contain the escape of radioactive steam or gas to a maximum pressure in the range of 40 to 80 psi
• The containment is the fourth and final barrier to radioactive release (part of a nuclear reactor’s defense in depth strategy), the first being the fuel ceramic itself, the second being the metal fuel cladding tubes, the third being the reactor vessel and coolant system

Fukushima Dai-Ichi plant
In the United States, Title 10 of the Code of Federal Regulations, Part 50, Appendix A, General Design Criteria (GDC 54-57) or some other design basis provides the basic design criteria for isolation of lines penetrating the containment wall.

Each large pipe penetrating the containment, such as the steam lines, has isolation valves on it, configured as allowed by Appendix A; generally two valves.

For smaller lines, one on the inside and one on the outside.

For large, high-pressure lines, space for relief valves and maintenance considerations cause the designers to install the isolation valves near to where the lines exit containment.

In the event of a leak in the high-pressure piping that carries the reactor coolant, these valves rapidly close to prevent radioactivity from escaping the containment.

Valves on lines for standby systems penetrating containment are normally closed.
• The containment isolation valves may also close on a variety of other signals such as the containment high pressure experienced during a high-energy line break (e.g., main steam or feedwater lines)
• The containment building serves to contain the steam/resultant pressure, but there is typically no radiological consequences associated with such a break at a pressurized water reactor

Thank you!

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Renewables & Distributed Energy Resources

Erol Chartan
National Renewable Energy Laboratory

Energy Bar Association
Golden, CO
Feb. 15-16, 2018

Agenda

• Renewables
  ▪ Wind
  ▪ Solar
• Distributed Energy Resources
  ▪ Storage
  ▪ Demand Response
  ▪ Electric Vehicles
  ▪ Integration Issues
Renewables – Wind

• Wind
  ▪ Evolution of wind capacity and technology
  ▪ Wind resource
  ▪ Offshore wind

Global Installed Wind Capacity

- Costs are becoming cheaper
- Turbines are becoming more effective
Texas has around 20,000 MW of wind power capacity.
Wind Turbine Size

- Turbines become higher to get cleaner and faster air
- New smart turbines can offer grid services

Global Wind Resource

- U.S. has some of the best resource in the world
Wind Power Curves

Wind Toolkit Power Curves

- Offshore
- IEC-1
- IEC-2
- IEC-3

Wind Speed (m/s)

Normalized Output

U.S. Wind Resource

- A turbine’s cut-in speed typically could be around 3.5 m/s
Offshore Wind Facts

• Over 10 GW of offshore wind installed globally
• 92% of installed offshore capacity in Europe
  ▪ Average water depth is 25 m
  ▪ Average distance to shore is 42 km
  ▪ The UK has twice as much offshore as onshore capacity

Why the North Sea?

• Very shallow water
• Many countries with renewable energy targets in near proximity
• Dense populations = less space
• Early adopters of onshore wind technology
Offshore Pros and Cons

- **Advantages:**
  - Generally higher capacity factors
  - Less visual impact
  - Often closer to load centers
  - Better correlation with load in some locations

- **Disadvantages:**
  - Higher installation costs
  - Maintenance issues
Floating Wind Turbines

Renewables – Solar

• Solar Photovoltaic
  ▪ Evolution of solar capacity and cost
  ▪ Solar Technologies
  ▪ Solar Resource
  ▪ Concentrated Solar Power
- Costs are becoming cheaper
U.S. PV Installations by State

PV Cost Learning Curve

Global average module price (2014 USD/W)

- 22% price reduction for each cumulative volume
- 2006 c-Si price increase due to polysilicon shortage

Cumulative production volume (MW)

- c-Si
- CIGS
- Other

- Economies of scale manufacturing
- Technology advances
- Other material costs
- Polysilicon price
Balance of System Costs

Table 1 lists all key system and company assumptions. Details of our residential modeling assumptions are included in Section 3.3.

![Graph showing the balance of system costs](image1)

- Module cost is a small proportion of the total cost
- Utility scale PV can reduce some of these cost proportions

Solar Energy Technologies

<table>
<thead>
<tr>
<th>Photovoltaic</th>
<th>Concentrated Solar Power</th>
<th>Solar Heating</th>
<th>Solar Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV systems use semiconductors to convert sunlight directly to energy.</td>
<td>CSP systems focus the sun’s heat onto a generator to produce electricity.</td>
<td>Solar collectors absorb the sun’s energy to provide low temperature space or water heating.</td>
<td>Passage for natural interior lighting or piping light indoors using fiber optics.</td>
</tr>
</tbody>
</table>

**Energy Conversion**

- Light $\rightarrow$ Electricity
- Heat $\rightarrow$ Electricity
- Heat $\rightarrow$ Heat
- Light $\rightarrow$ Light

**Conversion Type**

- Direct
- Indirect
- Direct
- None
Atmospheric Effects

- Atmosphere
- Solar Irradiance
- Absorbed Radiation
- Diffuse Radiation
- Clouds
- Earth
- Direct Radiation

CSP Technologies

- Parabolic troughs
- Linear Fresnel Reflectors
- Central Receiver / Heliostats
- Parabolic dishes
Ivanpah Solar Electric Generating System

- Opened in 2014
- 392 MW capacity
- World’s largest CSP plant
- 173,500 heliostats
- Cost: $2.2 Billion

Ivanpah Solar Electric Generating System (cont’d)
Unlike flat-plate photovoltaic (PV) technologies, which can use diffuse sunlight to generate electricity, CSP requires Direct, Normal Irradiance, DNI.

CSP and PV plants within 30 miles of each other
PV shows more variability
Even without a multi-hour storage system, CSP has inherent short-term storage in the form of thermal inertia.
Distributed Energy Resources – Storage

- Storage
  - Value of Storage
  - Storage technologies – capacitors, fly wheels, compressed air energy storage, batteries, pumped hydro

Value of Storage

Source: EPRI – Electricity Energy Storage Technology Options, 2010

- T&D = Transmission and Distribution
- DESS = Distributed Energy Storage System
Duck Curve

Growing need for flexibility starting 2015

Storage Technologies

Grid Energy Storage Technologies and Applications

Source: Electropaedia
**Battery Technologies**

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Acid</td>
<td>Inexpensive</td>
<td>Low energy density</td>
</tr>
<tr>
<td></td>
<td>Mature technology</td>
<td>Low number of cycles</td>
</tr>
<tr>
<td></td>
<td>Low maintenance</td>
<td>Limited full discharge cycles</td>
</tr>
<tr>
<td></td>
<td>Low self-discharge</td>
<td>Environmentally bad to build</td>
</tr>
<tr>
<td>Nickel Cadmium</td>
<td>Fast charging</td>
<td>Low energy density</td>
</tr>
<tr>
<td></td>
<td>High no. of charging cycles</td>
<td>Needs to be cycled</td>
</tr>
<tr>
<td></td>
<td>Good performance in cold</td>
<td>Toxic metals</td>
</tr>
<tr>
<td></td>
<td>Low cost per cycle</td>
<td>High self-discharge</td>
</tr>
<tr>
<td>Lithium Ion</td>
<td>High energy density</td>
<td>Expensive to manufacture</td>
</tr>
<tr>
<td></td>
<td>Mature technology</td>
<td>Low no. of charging cycles</td>
</tr>
<tr>
<td></td>
<td>Low self-discharge</td>
<td>Low maintenance</td>
</tr>
<tr>
<td>Flow</td>
<td>Large energy potential</td>
<td>Low energy density</td>
</tr>
<tr>
<td></td>
<td>Fixed power costs</td>
<td>New technology</td>
</tr>
<tr>
<td></td>
<td>Long cycle life</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quick response times</td>
<td></td>
</tr>
</tbody>
</table>
Pumped Hydro Storage

- Remember Mt. Elbert?
- Large Power Ratings – 200 MW here
- Large Energy Capacities from Reservoirs
- Very location specific – difficult to build new plants

Distributed Energy Resources – Demand Response

- Demand Response
  - Demand – consumption, variability and uncertainty
  - Demand Response Services and Availability
Power System Objective

Supply electric power to customers

- Reliably
- Economically

Consumption and production must be balanced continuously and instantaneously

Maintaining system frequency is one of the fundamental drivers of power system reliability

Load by Sector

2013 Total Electric Industry
(Share of Megawatthours Sold)

- Residential: 37.4%
- Commercial: 30.1%
- Industrial: 26.3%
- Transportation: 0.2%

Source: (U.S. Department of Energy - Energy Information Administration)
Load Variability and Uncertainty

Demand-Side Management – Traditional

- Demand Response for Peak Shaving
  - Air Conditioners
  - Water Heaters
- Industrial
  - Qualified Demand Response
  - ERCOT Spinning Reserve

Source: AWEA
Peak Shaving Example

an example: ISO-NE electric load, June 24, 2010

Demand Response Services

<table>
<thead>
<tr>
<th>Product</th>
<th>Purpose</th>
<th>Response Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td>Response to random unscheduled deviations in scheduled net load</td>
<td>Called continuously, must begin response w/in 30 seconds, energy neutral over 15 minutes</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Additional load following reserve for large un-forecasted wind/solar ramps</td>
<td>Called continuously, must begin response w/in 5 minutes</td>
</tr>
<tr>
<td>Contingency</td>
<td>Rapid and immediate response to a loss in supply (≤ 30 minutes)</td>
<td>Called once per day or less, must begin response w/in 1 minute</td>
</tr>
<tr>
<td>Energy</td>
<td>Shed or shift energy consumption over time (≤ 1 hour)</td>
<td>Called 1-2 times per day, 4-8 hours advance notification</td>
</tr>
<tr>
<td>Capacity</td>
<td>Ability to serve as an alternative to generation</td>
<td>Must be available 20 hours in each area</td>
</tr>
</tbody>
</table>

Source: NREL
Distributed Energy Resources – Electric Vehicles

- Electric Vehicles
  - Existing EVs
  - Impacts of Charging EVs
U.S. 2016 EV Sales

- U.S. just sold its 500,000th EV in 2016

Source: InsideEVs.com

Worldwide EV Market Share

- PEV Market Share – as percentage of new vehicle sales (2015)
  - 1. Norway – 22.39%
  - 2. Netherlands – 9.74%
  - 3. Iceland – 2.93%
  - 4. Sweden – 2.62%
  - 5. Denmark – 2.29%
  - ...
  - 10. China – 0.84%
  - U.S. – 0.66%

Source: EVsales.com
<table>
<thead>
<tr>
<th><strong>Tesla Model S</strong></th>
<th><strong>Nissan Leaf, 2018</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price:</strong> approx. $62,700 - $118,200</td>
<td><strong>Starting price:</strong> $29,900</td>
</tr>
<tr>
<td><strong>Battery Size:</strong> 75 - 100 kWh</td>
<td><strong>Battery Size:</strong> 40 kWh lithium-ion</td>
</tr>
<tr>
<td><strong>Range:</strong> approx. 190 - 300 miles at 70 mph</td>
<td><strong>Range:</strong> 151 miles</td>
</tr>
<tr>
<td><strong>Motor:</strong> 284 - 568 kW (380 - 761 HP)</td>
<td><strong>Motor:</strong> 147 HP</td>
</tr>
</tbody>
</table>
Chevrolet Volt (Hybrid) 2018
• Price: $34,095
• Battery Size: 18.4 kWh
• Range: 53 miles (electric) + 420 miles (gas extended)
• Motor: 111 kW (147 HP) + 1.5 liter gas

Source: Chevrolet

BMW i3
• Price: $44,450
• Battery Size: 33 kWh lithium-ion
• Range: 124 miles
• Motor: 170 HP

Source: BMW
Understanding EV Impacts

- Vehicle type (battery size)
- Charging type and location
  - Speed to charge?
  - Home charging only?
  - Public charging infrastructure?
- Driving patterns and timing
  - Urban or rural
  - Weather conditions
  - Weekend or weekday?
  - Multiple drivers?
- Charging timing
  - Unconstrained?
  - Utility controlled?
  - Incentivized? (Time of use or off peak pricing?)

Household Impacts

Fig. 4. Breakdown of electricity consumption of an average Californian household in summer with the addition of PHEVs.

Source: Huang, et al., Energy Policy, 2011
Bulk Impacts of Charging Profiles

- Load
- Power system prices
- Power system emissions
- Congestion

Where Can EV Charging Aid Renewables Integration?

- Regulation reserve?
- “Gap-filling”
- Reduced curtailment
- Compensating for forecast errors?
- Would you like to participate in these services if you owned an electric vehicle?
Distributed Energy Resources – Integration Issues

• Integration Issues
  ▪ Standards
  ▪ Inverter high level view
  ▪ Potential impact on the distribution grid and transmission

Importance of IEEE 1547

• Energy Policy Act (2005) Cites and requires consideration of IEEE 1547 Standards and Best Practices for Interconnection; all states use or cite 1547.
• Energy Independence and Security Act (2007) IEEE cited as a standards development organization partner to NIST as Lead to coordinate framework and roadmap for Smart Grid Interoperability standards and protocols (IEEE 1547 & 2030 series being expanded);

NIST: National Institute of Standards and Technology

Interoperability: The capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely and effectively
Importance of IEEE 1547 (cont’d)

IEEE 1547 Interconnection Standards Example Use in United States

IEEE 1547 Interconnection System and Test Requirements
- Voltage Regulation
- Ride-through
- Grounding
- Disconnects
- Interoperability
- Islanding
- Etc.

IEEE 1547.1 Conformance Test Procedures
- Utility Interactive tests
- Islanding
- Reconnection
- O/U Voltage and Frequency
- Synchronization
- EMI
- Surge Withstand
- DC Injection
- Harmonics

UL 1741 Interconnection Equipment Safety and Performance Certification
- 1547.1 Tests
- Construction
- Protection against risk of injury to persons
- Rating, marking
- Specific tests for various technologies

National Fire Protection Association (NFPA)

IEEE 1547 (1547.1) supplements and is to be used in conjunction with

*NFPA 70 (NEC)*
- Article 690 PV Systems
- Article 705: Interconnection systems (shall be suitable per intended use per UL1741)
Other articles:
- 480 Storage Batteries
- 692 Fuel Cell Systems
- 694 Wind Electric

Inverter – High-Level View

- Inverters: Convert variable direct current (DC) output to alternating current (AC)
- They effectively convert the electric output of solar generators, for example, to a usable form of electricity
Modern inverters have:
1. Sophisticated monitoring and communication of the grid status
2. The ability to receive offsite operation instructions
3. The capability to make autonomous decisions to maintain grid stability and reliability

Modern inverters can provide:
1. Voltage
2. Current
3. Positive / Negative real power
4. Positive / Negative reactive power
5. Active voltage regulation
6. Active frequency regulation

- Transmission lines all have different resistance, inductance and capacitance which affects the voltage
- Varying demand and generation affect the current
- Different electrical appliances, loss of a transmission line and more can cause a change in reactive power
Other Potential Impacts on Distribution Grid and Transmission

- Constant development of IEEE 1547
- Smart Grids – communications and information technology
- Changing transmission constraints from different build locations
- New contingencies
Thank you !

Erol Chartan

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Thank You to Our Host and Instructors from WAPA

Western Area Power Administration

Electric Power Training Center
Golden, Colo.
https://www.wapa.gov/EPTC/Pages/eptc.aspx

Providing the highest quality power system operations training for audiences of all levels, with fully operational power system simulators for student experiential learning.