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](https://goo.gl/maps/a2ZaC96F8Jm) is a PDF of the map and directions. Parking is free in this area.

URL for the address [https://goo.gl/maps/a2ZaC96F8Jm](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 - 4:00 pm:

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

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.
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

Informal and conversational – questions and comments encouraged.
• Day One
  ▪ Introductory Concepts
  ▪ Distribution Systems
  ▪ Transmission Systems

• Day Two
  ▪ Conventional Generation
  ▪ Renewables
  ▪ Distributed Energy Resources

Introductory Concepts
Kyle Conroy
Western Area Power Administration
Energy Bar Association
Golden, CO
Feb. 15-16, 2018
Agenda

The fundamental characteristics of electrical power
- Definitions of electrical characteristics
- Types of electrical power
- Energy measurement
- Diagram of an electrical grid

Electrical Characteristics

Voltage
- Electromotive Force (EMF)
- Potential Difference
- The pressure that drives electron movement
**Electrical Characteristics (cont’d)**

**Current**
- Electrical Charge
- Potential Difference
- The pressure that drives electron movement

**Types of Electrical Energy**

- **Direct Current (DC)**
  - Battery (chemical)

- **Alternating Current (AC)**
  - Electric Generator
AC systems in North America operate at 60 cycles/sec
- 60Hz Frequency
- Why 60 hertz?
Early isolated systems used various frequencies
- Nicolas Tesla (late 1880’s) chose 60 hertz to reduce flicker in street lighting
- Change is an issue of economics
- 50 hertz in Europe
- 60 hertz in USA
Electrical Power – Watts

Power is a product of voltage and current

\( P = V \times I \) measured in Watts

- 750 watts = 1 horsepower
- Kilowatt (kW) = 1000 watts
- kWh = kilowatts used in an hour
- Megawatt = 1,000,000 watts
- mWh = megawatts used in an hour

Reactive, Real & Apparent Power

Real Power – measured in watts
- The portion of power flow that, averaged over a complete cycle of the AC waveform, results in net transfer of energy in one direction

Reactive Power – volts-amperes reactive (Vars)
- The portion of power flow due to stored energy, that returns to the source in each cycle

Apparent Power – measured in volts-amperes
- Vector sum of Real and Reactive Power
Total power flow is composed of two parts:
- Real Power, $P$ in MW
- Reactive Power, $Q$ in MVAR

Total Power, $S$ in MVA
- Equals the Vector sum of $P$ and $Q$

$$S = \sqrt{P^2 + Q^2}$$

**Power Factor**

Ratio between real and apparent power
- Real Power / Apparent Power

Number between 0 and 1
- If $pf = 0$, energy flow is purely reactive
  - Not good!
- If $pf = 1$, energy flow is entirely consumed by the load.
  - Ideal!
Reactive Power – Power Factor Correction

Reactive power can be adjusted with capacitors and inductors

- Capacitors
  - Store energy in an electric field
  - Electric charges collect on the conductors creating an electric field between the conductors

Capacitors are used in transmission systems, to counteract inductance and increase system voltage.

- Inductor
  - Stores energy in a magnetic field
  - Coiling the wire concentrates the magnetic field through the center of the coil
  - Referred to as reactors in transmission systems

Inductors are used in transmission systems, to counteract capacitive reactance and depress system voltage.
U.S. Electrical Grid

Interconnections
Thank you!

Kyle Conroy
Agenda

Distribution Systems
  • Definition of electrical distribution systems
  • Description of Network and Radial distribution
  • Distribution metering
  • Distribution operational issues, concerns and practices
  • Distribution protection schemes

Electrical Distribution System

While the transmission system delivers high-voltage electricity from generators to substations, the distribution system:
  • Reduces the voltage and then delivers the electricity to retail customers
  • In addition to substations, the distribution system includes wires, poles, metering, billing, and related support systems involved in the retail side of electricity delivery
Electrical Distribution System (cont’d)

Distribution voltages generally classified as a range from 5 kV to 35 kV
- The four major voltage classes are 5, 15, 25, and 35 kV
- Distribution voltage class is based upon the capacity of associated equipment and components
- It is not the actual operating voltage

Electrical Distribution System (cont’d)

As seen here, the most common distribution system in service operates in the 15-kV class (12.47- and 13.8-kV)
Electrical Distribution System

Radial Distribution

230/13.8kV

120/240V Residential

120/240V 3-phase Commercial

120/208V 3-phase Light Commercial

120/240V Residential

120/240V Residential

120/240V Residential

120/240V Residential
Metering is essential to achieve power quality, power flow and power consumption

- Volts, Amps (volt-amps) and VARs provide a picture of power quality
- Power flow data is also an indicator of the health of the system
- Power consumption (a/k/a revenue metering, is a consumer-driven measurement)

Metering (cont’d)

- Metering provided from the source (or substation) reflects:
  - Volts and Amps (volt-amps)
  - Watts
  - VARs

230/13.8kV
Metering (cont’d)

• As measured through a combination of
  ▪ Current Transformers 230/13.8kV
  ▪ Potential Transformers

Metering (cont’d)

• As measured through a combination of
  ▪ Current Transformers
  ▪ Potential Transformers 230/13.8kV
Metering (cont’d)

• As measured through a combination of
  ▪ Current Transformers
  ▪ Potential Transformers
  ▪ Various meter styles & types

Metering (cont’d)

• Revenue Metering
  ▪ Residential
Metering (cont’d)

• Revenue Metering
  ▪ Residential
  ▪ Commercial
• Safety
  ▪ While installing replacement batteries in a substation, an electrical fault occurred when a battery cable fell onto the terminals on one of the installed batteries – the ensuing electric arc:
    ▪ Severely burned and melted his rubber insulating gloves
    ▪ He sustained second- and third-degree burns, requiring several surgeries, and multi-day hospitalization
  ▪ While descending a utility pole a worker fell about 10 meters to the ground – pole climbers cut out
    ▪ He sustained fractured ribs, fractured pelvis, fractured legs, and internal injuries and was hospitalized for 14 days

https://www.osha.gov/dsg/power_generation/index.html

• Safety (cont’d)
  • While a power line worker was moving his aerial lift platform away from a utility pole after completing repairs, a tractor-trailer struck the aerial lift truck, ejecting the worker from the platform
    ▪ He died of injuries sustained in the fall
  • Short-circuit current

https://www.osha.gov/dsg/power_generation/index.html
Operational Issues (cont’d)

• Reliability
  • The goal of a power system is to supply electricity to its customers in an economical and reliable manner
  • The cost of interruptions and power outages can have severe economic impact on the utility and its customers
  • Distribution system reliability should be on par with the G & T systems to achieve greater customer satisfaction without additional operational cost
  • Reliability assessment of a distribution system is concerned with the performance at the customer load points

Operational Issues (cont’d)

• Reliability (cont’d)
  • Basic parameters used to evaluate the reliability of a distribution system can be categorized as load point indices and system reliability indices
    ▪ The load point failure rate (ê)
    ▪ The average outage time (r) and average annual unavailability or outage (U)
    ▪ The set of system reliability indices includes interruption indices and energy oriented indices
  • Distribution company to have proper planning tools to assess and improve its reliability and performance
Operational Issues (cont’d)

- System Reliability Indices
  - System Average Interruption Frequency Index (SAIFI)
  - System Average Interruption Duration Index (SAIDI)
  - Customer Average Interruption Duration Index (CAIDI)
  - These indices (SAIFI, SAIDI and CAIDI) express in terms of system customers
  - A customer here can be an individual, firm, or organization who purchases electric services at one location

http://shodhganga.inflibnet.ac.in/bitstream/10603/10247/9/09_chapter%204.pdf

Thank you!
Kyle Conroy
(Log into SEL account to access Synchrophasor Demo.)
Agenda

• Distribution (part II)
  ▪ Transformers
  ▪ Down-line Automation
  ▪ Distribution SCADA, Control Room Operations
  ▪ Bi-directional Distribution Systems

Agenda (cont’d)

• Transmission
  ▪ Definition
  ▪ Voltages
  ▪ Transmission Equipment
  ▪ Operational Issues
  ▪ Transformers and Substations
  ▪ SCADA, Control Room Operations
  ▪ Phase Shifters
  ▪ Phasor Measurement Units
  ▪ Fiber in Neutral Grounds
  ▪ Drones
  ▪ Vegetation Management
• The purpose of a transformer is to “step up” or “step down” voltage
  ▪ Stepping up voltage reduces losses
  ▪ Stepping down is required for consumption
Transformers (cont’d)

A transformer is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. A varying current in one coil of the transformer produces a varying magnetic field, which in turn induces a varying electromotive force (emf) or "voltage" in a second coil. Power can be transferred between the two coils through the magnetic field, without a metallic connection between the two circuits.

https://en.wikipedia.org/wiki/Transformer

Distribution Transformers

- Distribution voltage (usually) less than 100,000 Volts (100 kV)
- Transformers rated at less than 200 MVA (typically 5-to-100 MVA)
- Most common voltages include 69 kV, 34.5 kV, 13.8 kV, 13.2 kV or lower
- Three phase and single phase
- Often multiple taps on low side to serve multiple feeds
- Load Tap Changing (LTC) transformer allow “boosting” of distribution system voltages when loading is high and system voltages sag to less than 0.95% of nominal
- Example: 13.8 kV * 0.95 = 13.11 kV (690 Volt drop / difference)
- Direct connection to load, loading less constant
A distribution transformer is designed for maximum efficiency at 60% to 70% rated load and normally doesn't operate at full load all the time. Its load depends on distribution demand, varying more than transmission transformers.

In a transmission-level transformer, the flux density is higher than in a distribution transformer. Its maximum efficiency generally occurs at higher rated loading levels (> 90%).

Size Range for Distribution Transformer Classification

- Distribution Substation
- Pole Mounted Distribution
• In the US, there are 200,000 distribution circuits comprised of:
  • 6 Million miles of distribution lines
  • Serving 160 million electric customers

• Outage Metrics – highlighting the need for enhanced automation

• Automation includes:
  ▪ Protective relays
  ▪ Automation Controllers
  ▪ Fault Circuit Indicators (FCI's)

Distribution Automation – Results From The Smart Grid Investment Grant Program
Distribution Automation

- Distribution automation (DA) uses digital sensors and switches with advanced control and communication technologies to automate feeder switching; voltage and equipment health monitoring; and outage, voltage, and reactive power management.
- Automation can improve the speed, cost, and accuracy of these key distribution functions to deliver reliability improvements and cost savings to customers.
Distribution Protective Relay Applications

- Distribution Feeder Protection
- Breaker Failure Protection
- Generator Intertie Protection
- Recloser Control
- Synchronism Check
- Underfrequency Load Shedding
- Undervoltage Load Shedding

Automation Control
Automation Control (cont’d)

- **Outage Minimization**—Reduce system impacts by integrating reclosers and controls into distribution system. Improve reliability by maintaining service to loads not on the faulted segment of the feeder.
- **Distributed Generation Protection**—Protect both the utility and independent power producer with one device. Apply directional protection and while using different protection settings for faults in either direction. Protects from voltage angle differences by enabling synchronism check before closing.
- **Load Shedding**—Use underfrequency and undervoltage elements to implement basic load-shedding schemes. More advanced load shedding schemes employ rate-of-change-of frequency (ROCOF) elements to shed load.

Automation Control (cont’d)

- **Communications-Assisted Protection Schemes**—Integrates with Ethernet or serial based comm networks utilizing DNP3, Modbus or optional IEC 61850. Use communications for local/remote engineering access, SCADA, real-time protection and control, loop restoration, islanding detection, blocking, and fast bus tripping schemes.
- **Inrush Detection**—Detect transformer energization or motor startup and block tripping for inrush conditions with a second-harmonic blocking element. Implement harmonic detection, blocking selected tripping elements until the inrush subsides.
• **Synchrophasors Improve Performance**—Apply synchrophasors in distribution applications to identify island conditions.

• **Fault Location**—Combine fault indicators with recloser controls to pinpoint the exact fault locations, even on lateral feeds. When a fault occurs, the recloser control reports the distance from the recloser to the fault; however, for lines with branches, the recloser control cannot determine on which branch of the line the fault has occurred. By following the line along the tripped fault indicators, the line crew can easily find the fault area.

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**Fault Circuit Indication**

- Fault Indicators provide 360 degree rotational flash sequence enhances fault display location
- Permanent and momentary faults are identified via red and amber LEDs and flash patterns
- Identifies momentary faults with flashing amber-colored LEDs.
- Permanent faults indicated alternating red and amber LEDs.
- Quick and easy to install with one hot stick
- Detect momentary faults before they become outages and speed restoration after permanent faults
**Supervisory Control And Data Acquisition**

Manages 3 types of data for grid visibility: AI, DI & DO

- Analog Inputs (AI) – **Analogs**: Voltages, currents, fault distances
- Digital Inputs (DI) – **Status**: Breaker status (Open/Closed), Recloser Status (on/off), Breaker Alarms, Transformer Alarms, Lockout Alarms (tripped/normal)
- Digital Outputs (DO) – **Controls**: Breaker Open/Close, Reclosing, Hot Line Orders (HLO’s), Load Tap Changers (LTC’s), Yard Light Control

**Distribution SCADA/Control Room Ops**
Bi-directional Distribution Systems

- A distribution system where power not only flows to load, but Distributed Generators (DG) put power back on to the grid
- Power flows in both directions on the distribution network, not just in the direction of the load
- Protection equipment is required to understand power flow in both directions
- Relay actions take place regardless of power flow direction
- Additional features may be needed to accommodate equipment

Transmission – Definition

- Transmission in the Bulk Electric System (BES) makes it possible to move large quantities of power generated at remote locations across large distances to the load centers where it is consumed
- Bulk production reduces cost per MW/hr – economies of scale
- Transmission requires conductors suspended from towers hanging off insulators
  - Fast construction
  - Environmental issues
  - ROW issues
Voltages are expressed in thousands of volts, kilo-volts (kV)
• 230 kV = 230,000 Volts
• Residential service: 120/240 VAC
• Industrial voltages: 240 VAC – 600 VAC, VAC 480 VAC most common
• Primary Distribution
• Secondary Distribution
• Transmission
  - Sub-Transmission / Distribution: 115 / 138 / 161 / 230 kV
  - Transmission: 230 / 345 / 500 / 768 / 1000 kV

Why create and use high, dangerous voltages?

Losses!!

Power (P) is a product and Voltage (V) and Current (I):
\[ P \text{ (watts)} = V \text{ (volts)} \times I \text{ (amps)} \]

Power Losses (\( P_L \)) are a product of Current (I) and Resistance (\( \Omega \)):
\[ P_L \text{ (watts)} = I^2 \text{ (amps)} \times R \text{ (ohms)} \]
Transmission – Losses (cont’d)

Power Loss vs Voltage Level Example:

\[ P = V \times I \quad \rightarrow \quad 120 \, \text{V} \times 10 \, \text{A} = 1200 \, \text{W} \]

If resistance = 5Ω (\( P_L = I^2 \times R \)) \( \rightarrow \) \( 10^2 \, \text{A}^2 \times 5 \, \Omega = 500 \, \text{watts} \)

\[ P = V \times I \quad \rightarrow \quad 1200 \, \text{V} \times 1 \, \text{A} = 1200 \, \text{W} \]

If resistance = 5Ω (\( P_L = I^2 \times R \)) \( \rightarrow \) \( 1^2 \, \text{A}^2 \times 5 \, \Omega = 5 \, \text{watts} \)

Transmission Equipment

Power Circuit Breaker (PCB)
- Current technology utilize a sealed chamber containing Sulfur Hexafluoride (SF₆) gas
- Breaker operation interrupts flow of current, essentially halting massive amount of energy
- Energy interruption results in a fire / explosion
- SF₆ gas within chamber is forced with high pressure at electric arc
- Arc quenched via SF₆ gas “extinguisher”
- Resultant (solid) residue / powder kills healthy lung tissue (if inhaled) – no recovery
Power Circuit Breaker (PCB)

- Analogous to circuit breaker in home – MUCH larger

**Home PCB:**
- Operates at 120 or 240 V
- Interrupts 15 – 200 A

**Transmission PCB:**
- Operates between 115 <-> 1000 kV
- Interrupts 1000 – 5000 A

Transmission Equipment (cont'd)

Transmission Equipment (cont’d)

Towers
- Single Wood Pole
- Wood Pole “H”
- Lattice Steel
- Tubular Steel
- Fiber or “Spun” construction
- Crossarms, Conductor, Insulators, Overhead Ground Wire (OHG), Stand Off Insulators, Take of Structures, Dead End Structures, Turning Structures
- Underground
- 3 Conductors for AC: 2 conductors for DC
- DC transmission requires expensive converter stations

Distribution lines
Distribution lines are the smaller, lower voltage lines that carry electricity from the substation to your home or business.

Padmount box
Padmount transformers transfer electricity to underground power lines.
Transmission Equipment (cont’d)

**Insulators**

- An insulator consists of a material that does not conduct an electric current, under the influence of an electric field
- Perfect insulators do not exist – glass, paper and Teflon, which have high resistivity, are very good electrical insulators
- Insulators support and separate electrical conductors inhibiting current flow
- 3 common materials: Glass, Porcelain and Polymer (Polymeric / Composite)
- Pin, Suspension, Strain & Shackle
- Advantages and disadvantages to each
- One may have optimal application
<table>
<thead>
<tr>
<th>INSULATOR TYPE</th>
<th>ADVANTAGES</th>
<th>LIMITATIONS</th>
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<tbody>
<tr>
<td>Porcelain</td>
<td>• Long history of use</td>
<td>• Weight</td>
</tr>
<tr>
<td></td>
<td>• Performance quantified</td>
<td>• Hidden defects</td>
</tr>
<tr>
<td></td>
<td>• Easily interchangeable</td>
<td>• Susceptible to vandalism</td>
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<tr>
<td></td>
<td>• Reduced right of way with line posts</td>
<td>• In-service defect detection techniques not foolproof</td>
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<tr>
<td>Toughened Glass</td>
<td>• Long history of use</td>
<td>• Negative perception that glass is fragile</td>
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<tr>
<td></td>
<td>• Performance quantified</td>
<td>• Weight</td>
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<tr>
<td></td>
<td>• Damaged units easy to spot</td>
<td>• Attractive to vandals</td>
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<tr>
<td></td>
<td>• Easily interchangeable</td>
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<tr>
<td>Composite/NCI</td>
<td>• Reduced right of way with line posts</td>
<td>• Brittle fracture remains an issue with older units</td>
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<td></td>
<td>• Good contamination performance</td>
<td>• Aging due to the organic nature of components</td>
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<tr>
<td></td>
<td>• Lightweight</td>
<td>• Not easily interchangeable due to multitude of designs</td>
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<tr>
<td></td>
<td>• Reduction in installation costs</td>
<td>• Can have hidden defects</td>
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<tr>
<td></td>
<td>• Perception that it is less attractive to and not easily damaged by vandals</td>
<td>• Live-line techniques not yet perfected</td>
</tr>
</tbody>
</table>

Transmission Equipment (cont’d)

Insulators

![Power line with ceramic insulators](https://upload.wikimedia.org/wikipedia/commons/a/c/Power_line_with_ceramic_insulators.jpg)

![Insulator](https://en.wikipedia.org/wiki/Insulator_%28electricity)
Conductors

- Early conductor materials predominantly copper
- Evolved to commonly used Aluminum Conductor Steel Reinforced (ACSR)
- Composite Core Technology replaces steel core with carbon basted materials

Transmission Operational Issues

Safety

- Safety is of prime importance within industry
- Hazards include – electrocution, burns, heavy equipment accidents, falling, crushing, automobile accidents, soft tissue damage, long term exposure
- Some craftsman drive in excess of 50,000 miles/year (within 45 weeks)
- Removing equipment from service for maintenance is directed under scripted “switching” programs
Reliability

- Reliability is measured via SAIFI, SAIDI and other metrics.
- The reliability “arm” of the BES is not allowed to share information that could allow marketing divisions to “game” the system.
- Reliability is directly tied to maintenance programs.
- Reliability is not static, constant effort are made to remain compliant at all times.
- Reliability standard are not static and constantly evolving.
- North American Electric Reliability Corporation (NERC) sets forth compliance standards that address reliability issues.
- Not meeting Compliance Standards are punitively and/or monetary fines.

Thermal Limits

- Thermal limits refer to the maximum operating temperature of equipment.
- Directly related to the amount of energy being transferred across the material.
- Thermal limits are calculated based on physical properties of materials, location, wind speed, elevation etc.
- Issue is typically addressed in the planning stages of design.
- Equipment includes: Generators, transmission lines, transformers and energized, current carrying devices.
- Best though of as the heating of wires.
Transmission Operational Issues (cont’d)

Thermal Limits – Maintenance Sidebar

• So important, an entire industry has been created at recognizing thermal violations
• Thermography Scans a routine part of some maintenance programs
• Forward Looking Infrared (FLIR)
• Easy to detect problems BEFORE they impact reliability
• Older construction may be approaching thermal limits
• Evaluation of component limits may have been overlooked when additions occurred years later

http://www.flir.com/instruments/electrical/display/?id=49522
Unmanned Air Systems (UAS) with FLIR technology

Transmission Operational Issues (cont’d)

Stability Limits

• **Transient Stability Limits:** Typically defined as: “maximum power transfer or load level that ensures critical transient reliability criteria are met”
  - Transmission Operators establish SOLs to prevent unit/intra-area instability, inter-area instability, or tripping of facilities due to out-of-step conditions

**Stability Limits**

- **Voltage Stability Limits**: Typically defined as “the maximum power transfer or load level for which a post-Contingency solution can be reached”
  - Transmission Operators typically stress Transmission Paths / Interfaces or load areas to the reasonably expected maximum transfer conditions or area load levels to determine whether steady state voltage Stability limits exist


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**Loop Flow**

- A regional or sub-regional issue
- The movement of electric power from generator to load by dividing along multiple parallel paths; it especially refers to power flow along an unintended path that loops away from the most direct geographic path or contract path

http://www.teachmefinance.com/Scientific_Terms/Loop_flow.html
Transmission Operational Issues (cont’d)

Ratings Methodologies

- BES will have Voltage and transient stability ratings
- All equipment has thermal ratings
- Many permutations within formulae to calculate equipment rating
- Factors include
  - Physical properties of materials
  - Elevation
  - Wind Speed (mostly for conductors)
  - Physical properties of conductor
Solid State Transformer / Sidney DC Tie

http://ethw.org/Milestone-Proposal:Virginia_Smith_HVDC_Converter_Station_with_Integrated_AC_Voltage_Control_Function

Solid State Transformer
SCADA

Manages 3 types of data for grid visibility: AI, DI & DO

Analog Inputs (AI) – **Analogs**
Digital Inputs (DI) – **Status**
Digital Outputs (DO) – **Controls**

- All Protective relaying devices are polled (queried – "give me your data") via Remote Telemetry Unit (RTU) every 4 seconds
- 100,000+ data points are compiled and sent to Transmission System Operator (TSO) command center displays
- These displays are populated with the 3 data types to inform operators of BES state of health
3 Broad Categories (Desks)

- TSO – Transmission System Operation
- TSS – Transmission Scheduling Service
- AGC – Automatic Generation Control

Control Room Operations (cont’d)

Transmission System Operator (TSO)

- The “Central Nervous System” for the Bulk Electric System (BES)
- Remotely monitors (real time) and operates system components to maintain system integrity
- Directs switching programs
- Manages alarms, Operating limits, System integrity
- Controls Power Circuit Breakers (PCB’s), Reclosers, Hot Line Orders (HLO’s), Reactive support (via PCB’s), Load Tap Changers (LTC’s), Yard Lights and others
Control Room Operations (cont’d)

**TSO (cont’d)**

- Works with maintenance groups to isolate and de-energize equipment so field forces can safely maintain equipment without risk of electrocution
- Utilizes scripted “Switching Programs” that directs each step needed to make a safe work environment
### Control Room Operations (cont'd)

#### TSO (cont'd)

<table>
<thead>
<tr>
<th>Step</th>
<th>Event</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>TRS-1382/LS-Sw</td>
<td>CHECK in the &quot;LOCAL&quot; Position.</td>
</tr>
<tr>
<td>31</td>
<td>TRS-1382/LS-Sw</td>
<td>CHECK in the &quot;LOCAL&quot; Position.</td>
</tr>
<tr>
<td>34</td>
<td>TRS-1382</td>
<td>OPEN by MCH</td>
</tr>
<tr>
<td>35</td>
<td>TRS-1982</td>
<td>OPEN by MCH</td>
</tr>
<tr>
<td>36</td>
<td>TRS-1386</td>
<td>CHECK Open at the Breaker.</td>
</tr>
<tr>
<td>37</td>
<td>TRS-1385</td>
<td>CHECK Open and Tag [ ].</td>
</tr>
<tr>
<td>38</td>
<td>TRS-1986</td>
<td>CHECK Open at the Breaker.</td>
</tr>
<tr>
<td>39</td>
<td>TRS-1985</td>
<td>CHECK Open and Tag [ ].</td>
</tr>
<tr>
<td>40</td>
<td>TRS-2381</td>
<td>CHECK Open and Tag [ ]. (2nd Tag)</td>
</tr>
<tr>
<td>41</td>
<td>TRS-WW1A</td>
<td>CHECK Open and Tag [ ].</td>
</tr>
</tbody>
</table>
Transmission Scheduling Service (TSS)
- The “Stock Market” of the power industry
- Energy (MW) and transmission (capacity “Tags”)
- Combines long term, day ahead and spot market energy obligations to meet energy supply and demand for instantaneous consumption
- Load forecasts are generated 24 hours in advance by power serving entities, producing an estimated hourly demand
- Forecasts are historic and weather dependent
- Balancing Authority (BA) function manages (matches) load and demand, and monitors specific constrained transmission pathways

Automatic Generation Control (AGC)
- The “Cruise Control” of the energy industry
- Primary goal is to maintain stable system frequency
- Monitors system frequency and increases or decreases one or more generation units output (analogous to speedometer / accelerator position)
- Goal is to keep system frequency at 60 cycles/second (60 Hz)
- Frequency sags, generation increased
- Frequency rises, generation decreased
- One designated maintainer (BA) of within a region
Control Room Operations (cont’d)

TSS / AGC Consolidation

- Entitles are “turning over” their Scheduling and Generation responsibilities (TSS & AGC) to an independent manager
- Example: Southwest Power Pool (SPP)
- Utilizes a “market driven” approach to incentivize generation so system flows and reliability are maintained as before
- Example: Generation pricing at plants where connected transmission is lightly loaded will lure customers to buy lower priced commodity
- Benefits include management of assets savings to customers (ultimately, consumer)

Phase Shifters

- Loop Flow
- Overloads
Phasor Measurement Units

“Synchronized phasors (Synchrophasors) provide a real-time measurement of electrical quantities from across the power system. Applications include wide-area control, system model validation, determining stability margins, maximizing stable system loading, islanding detection, system-wide disturbance recording, and visualization of dynamic system response. The basic system building blocks are GPS satellite-synchronized clocks, phasor measurement units (PMUs), a phasor data concentrator (PDC), communications equipment, and visualization software.”


https://selinc.com/solutions/synchrophasors/

Optical Ground Wire (OPGW)

• Overhead Ground Wire (OHG)
• Optical Ground Wire (OPGW)
Line Patrol Helicopters vs. Drones

Line patrol, traditional helicopters
Tennessee Valley Authority (TVA) (0:39)

Energy drone program
Xcel Energy (3:22)
A Quick Look

Unmanned Aircraft Systems

Operational Excellence

(Video)

Vegetation Management

- P:\ME\Work Interest\LIDAR

Appendix – Example of One-Line Diagram

Appendix – Conversion Table

- 1 hp = 746 W
- 10 hp = 7460 W
- 100 hp = 74,640 W = 74 KW

- 1000w = 1 kw = 1.34 hp
- 10,000 = 10 kw = 13.41 hp
- 100,000 = 100 KW = 134.41 hp
- 1,000,000 = 1 MW = 1341 hp
Thank you!

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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.