DOE Office of Indian Energy Foundational Course Renewable Energy Technologies: Electricity Grid Basics Webinar (text version)

Below is the text version of the Webinar titled "DOE Office of Indian Energy Foundational Courses Renewable Energy Technologies: Electricity Grid Basics."

Amy Hollander:

Hello. I'm Amy Hollander with the National Renewable Energy Laboratory. Welcome to today's Webinar on Electricity Grid Basics sponsored by the U.S. Department of Energy Office of Indian Energy Policy and Programs. This webinar is being recorded from DOE's National Renewable Energy Laboratory's brand new state-of-the-art net-zero energy research support facility in Golden, Colorado.

This presentation on electricity grid basics is one of nine foundational webinars in the series from the DOE Office of Indian Energy and Education Initiative, designed to assist tribes with energy planning and development. The course outline for this webinar will cover: the DOE Office of Indian Energy Education Initiative that is sponsoring this webinar, a course introduction, the interconnection of electric power systems, technology overviews with four grid components and additional information and resources.

The DOE Office of Indian Energy is responsible for assisting tribes with energy planning and development, infrastructure, energy cost and electrification of Indian lands and homes. As part of this commitment, and on behalf of the US Department of Energy, Indian Energy is leading education and capacity building efforts in Indian country.

The foundational courses were created to give tribal leaders and professionals background information in renewable energy development that presents foundational information on the strategic energy planning, grid basics and renewable energy technologies that breaks down the components of the project development process on the commercial and community scale and that explains how the various financing structures can be practical for projects on tribal lands.

And with that, I'd like to introduce today's speaker, Dr. Ravel Ammerman. Dr. Ravel Ammerman is a teaching professor in the Electrical Engineering and Computer Science Department at the Colorado School of Mines. He also works as a research associate at the National Renewable Energy Laboratory. Dr. Ammerman received his PhD in engineering systems from the Colorado School of Mines in 2008. He has over 29 years of combined teaching, research and industrial experience. Dr. Ammerman has published in archival journals and has coauthored numerous award-winning technical articles.

And with that introduction, I will turn it over to Dr. Ammerman.

Ravel Ammerman:

Thanks, Amy, for that introduction. I appreciate the opportunity to provide some information about one of my favorite topics: the electricity grid.

This presentation is designed to give non-electrical professionals a basic fundamental understanding of large interconnected electric power systems. A large power system, like the one that provides electrical power to the United States, is commonly referred to as the "electricity grid." The electricity grid is a very complex system that may be subdivided into four major subsystems. Using the next slide, I'll provide an overview of the major components that comprise an interconnected power system. These are the topics I'll be describing during this webinar.

Electric power systems are real-time energy delivery systems. "Real-time" means that power is generated, transported and supplied the moment you turn on a switch. Generators must produce energy as a consumer calls for it. Two representations of the electricity grid are shown on this slide. Both figures show the basic building blocks of the electricity grid. The diagram on the top shows the basic system components, while the one on the bottom shows an electrical schematic diagram of the same system. Moving from left to right across the slide, the production of electrical energy starts with generation. A generating station transforms other sources of energy into electrical energy. The electrical energy is then transformed at a high transmission substation before being transported long distances over transmission lines.

As I will detail later in this presentation, high-voltage power lines are needed to efficiently transport the energy over long distances between the generation source and the industrial, commercial and residential customers. Distribution substations transform the high-voltage energy into low-voltage energy that is more suitable for delivery to its final destinations.

As described on the previous slide, a generating station transforms other sources of energy into electrical energy. The chart shows the generation mix currently used in the United States. Thermal energy for steam turbine power plans is produced by burning fossil fuels like coal and natural gas. Nuclear energy is also used to produce steam. Energy from falling water is used in a hydroelectric power plant. Power plants using these types of energy resources are commonly described as conventional or dispatchable designs. Non-dispatchable generators include those that convert renewable sources of energy like wind and solar into electricity.

Looking at the pie charts, there are some important observations to be made. First, the majority of electrical energy used in the US is generated by fossil fuel. The United States has large coal reserves is one reason for this. Nuclear energy accounts for 19 percent of the electricity generated in the US, and currently, the use of renewable resources, things like wind, biomass, geothermal and solar that are currently a very small percentage of the total. For example, wind has been responsible for a lot of the recent growth in the use of renewable resources, but currently it represents only three percent of the total generation mix.

During this webinar, you will be introduced to many of the important concepts of an interconnected power system. The basic processes involved in a conventional or dispatchable electricity generator are presented first. Then high-voltage transmission lines will be explored. Next, the key type of equipment found in substations will be discussed. And finally, primary distribution systems, both overhead and underground, will be covered. So you'll have the opportunity to learn how distribution systems provide electrical power to the end users.

Let's begin with an overview of conventional power generation. To illustrate how conventional thermal power plants produce electricity, I would like to begin by playing a short animation provided by the Tennessee Valley Authority on their website.

A quick summary of the highlights of the video we just watched: coal is pulverized and burned in a furnace to provide high-pressure and high-temperature steam. Steam turbine power plants convert steam energy into rotational energy that turns a generator shaft. An aspect that wasn't described in the animation is that once the energy of the super-heated steam has been transferred to the turbine, the remaining low-pressure steam is condensed back to water to be recycled. The overall efficiency is low, typically around 35 percent, largely because of the losses that occur in the thermal process. Steam turbine power plants can use coal, oil, natural gas or just about any combustible material as a fuel. Combustion byproducts include ash; CO2, or carbon dioxide, commonly implicated as one of the greenhouse gases; SO2, sulfur dioxide, or acid rain; and NOx, which stands for or abbreviates for nitrous oxide, or smog. Steam turbine power plants require a long time to start up and shut down, and this type of generation technology is proven and highly reliable.

Simple-cycle combustion turbine power plants burn fuel in the jet engine and use the exhaust gases to turn a turbine. The exhaust gases leave the turbine at very high temperatures. Simple-cycle combustion turbines do not make use of the exhaust gases, so the efficiencies are not very good, in the range 20 to 40 percent. A more effective approach is to use a combined cycle power plant. In this design, two stages of power generation are used: a combustion turbine and a steam turbine. The exhaust gases are used to heat steam, which is known as a heat recovery steam generator, or abbreviated a HRSG. With this design, overall efficiencies are greatly increased.

To summarize how combined-cycle combustion turbine power plants produce electricity, please now watch this short animation provided by the TVA. Nature holds the particles within an atom's nucleus together by a very strong force. If a nucleus of a large element like uranium-235 is split apart, large amounts of energy are released. Nuclear power plants use a controlled nuclear reaction to produce steam to drive a steam turbine. Given that nuclear power plants utilize steam turbines, they have low thermal efficiencies too. Since a controlled nuclear reaction is used, this type of generator takes a very long time to start and stop.

The reactor is housed inside a containment shell made of extremely heavy concrete and steel. A pressurized water reactor is pictured on this slide. The reactor and steam generator are both housed inside the containment structure, so the radioactive material is not allowed outside of this shell. Another type of design is called a boiling water reactor, which allows small amounts of radioactive material into the turbine system. Note that there is no smoke stack on this figure, indicating that no greenhouse gases are emitted. Radioactive waste disposal is a major concern of this technology.

To illustrate how conventional hydroelectric power plants produce electricity, I would like to begin by playing another short animation provided by the Tennessee Valley Authority.

A quick summary of the highlights of the video we just watched: hydroelectric power plants capture the energy of falling water using water held behind a dam, forming an artificial reservoir. As water is released from the reservoir, it spins a turbine that converts the water's energy into rotational energy. Within the generator, mechanical energy is converted to electricity. Hydropower is considered to be a renewable energy source because the water cycle is continuous and constantly recharging. Hydro units can be started quickly and brought up to full load in a matter of minutes.

Nevertheless, there are some environmental concerns associated with hydropower plants. Some examples include: land use, the inundation of resources and displacement of people, impact on the natural hydrology, meaning the increase in evaporative losses, altering river flows and natural flooding cycles, sedimentation and siltation. There are impacts on the biodiversity of aquatic ecology, fish, plants and mammals. There are water chemistry changes in mercury, nitrate and oxygen levels, and there are seismic risks associated if the structural dam were to fail.

Many of the turbine manufacturers had begun designing environmentally friendly turbines based on a potential market not only in the United States, but also worldwide. In 2002, the Department of Energy selected three projects where environmentally friendly turbines will be installed and tested. Two projects involved improving downstream fish passage, and one involves increased dissolved oxygen in discharged water. Other federal agencies and utilities are conducting research into hydro plants' operation to improve fish habitat.

Pump storage hydropower production is a method of storing electrical energy. Power is generated from water falling from a higher lake to a lower lake during peak load periods. An example of a peak load period would be a hot afternoon, when a lot of air conditioners are in operation. Then the operation is reversed during off-peak conditions. Examples would be late at night, early in the morning, when the majority of people are asleep, and during these off-peak conditions, the water is pumped from the lower lake back to the upper lake. This allows the utility to make use of less expensive surplus power when it's available during the off-peak times. And furthermore, the power company can obtain high-value power during the peak load generation periods by paying the lower cost to pump the water back during the off-peak periods.

A typical daily demand curve is shown on this slide. The example here is for the state of California, provided by the California Independence System Operator, or ISO. Power generation in megawatts is shown on the vertical axis, and the time of day is shown on the horizontal axis. This diagram is an effective way to illustrate the difference between electrical power and electrical energy. Power, measured in kilowatts or megawatts, represents the amount of installed capacity needed to meet the peak demand. Capital investments are required to build the power plants. Energy, measured in kilowatt hours or megawatt hours, represents actual work being performed. It is through the production and sale of energy that a company receives a return on their investment.

Using the same daily load curve, another important aspect of power generation can be shown. Remember that electric power systems deliver energy in real time. Generators must produce the energy as the demand calls for it. The portion of the load that must be met continuously, about 21,000 megawatts in this case, is picked up by what are called base load generating units. These are typically nuclear and coal-fired facilities. These generators are designed to run continuously 24 hours a day, 7 days a week at full load because of their long startup and shutdown times. The overall cost of production for these generators is low.

During a typical day, the load changes in a predictable fashion, and this change in demand is met by the intermediate generating units like combustion turbines and hydroelectric generators because they are easily controlled to follow the load. And finally, peak load must be met using peaking generating units like pump storage or other quick-starting standby and emergency units.

As we just saw in the preceding slide, the dispatching of generators is an important function of day-to-day power system operations. The system operators must decide what resources to use to effectively and reliably meet the system demand. This process can be extremely complex. The types of generators that have been described during this presentation are all considered dispatchable, or easy to control. Later in this webinar series, you will learn about other renewable energy options. Some of these sources are considered non-dispatchable. The introduction of non-dispatchable renewable energy generating units into the system means that the system operators have less control. The production of some type of renewable energy is variable and uncertain. Renewable energy from solar and wind resources require that the system operators use the energy whenever it is available. In other words, they must use it or lose it.

Next, we will briefly discuss high-voltage transmission systems. The vast interconnection of high-voltage transmission lines across the United States is pictured in the upper left-hand corner. The table on the right of the slide shows the typical transmission and subtransmission voltages that are used. Subtransmission voltages are used to transmit or transport energy over medium distances, typically across large populated areas. So a question: why do we use high-voltage transmission lines? The reason is that high-voltage transmission lines transport power over long distances very efficiently.

And some added background: high-voltage transmission allows you to take advantage of the power equation, and the power equation simply states that power is equal to the product of voltage times the current, meaning if the voltage is high, then the electrical current is reduced so we can use smaller wires. Further, the losses associated with transportation of electrical energy will be a function of the square of the current flowing in the conductors. In other words, both of these indicate we should strive to transmit power at the highest practical voltage to minimize losses and minimize the size of wire used.

Also on this slide you'll see various tower structures pictured. The lattice is in the lower left corner; the wood, lower right corner; and then tubular steel in the upper right corner. There are various advantages, disadvantages associated with these structures. Lattice can be easily modified. Wood towers are generally considered to be more aesthetic, and tubular steel requires a smaller right of way. So as you look at the pictures, you also notice that the transmission lines themselves are supported by insulators. This is necessary to prevent flash-over to the towers. And if you look closely, you'll notice as the voltage level goes up, the number of the insulators in the string has to increase too.

Substations utilized at the transmission level and the distribution level are known as transmission substations and distribution substations respectively. We will begin our discussion with a brief overview of the major equipment found in a typical transmission substation. Transformers are essential components in electric power systems, converting high-voltage power to low-voltage power, and vice versa. Generating plants use step-up transformers for high-voltage transmission and step-down transformers convert power to subtransmission and distribution voltage levels.

Circuit breakers are designed to interrupt current flowing in equipment when a problem occurs and the power has to be shut off. The breaker consists of a mechanical switch that opens a set of electrical contacts. Disconnect switches are devices used to isolate or de-energize equipment for maintenance purposes or repair. Disconnect switches have very low current-interrupt capabilities compared to circuit breakers, so the electrical load should be removed before they are opened. And then some other typical types of substation equipment include lightning protection, instrumentation and control and then what are called power factor correction capacitors.

Distribution systems are responsible for delivering electrical energy from a distribution substation to consumer service entrances, residential, commercial and industrial.

As illustrated by the picture, an obvious difference between transmission and distribution lines is the size and scale. In addition, transmission networks are constructed using multiple interconnected lines or paths, so the loss of a line or generator would not result in a loss of power to the consumers. Transmission networks are actively controlled, meaning that power maybe routed in various directions. Numerous large conventional power stations are connected to the transmission or subtransmission networks. On the other side, distribution systems are designed for power transport in only one direction: towards the consumers. This is an example of a passively controlled system. Some various distribution system voltages used in the United States are shown in the table pictured on this slide. This table is not an absolute in that some power companies may designate their system voltages differently. Radio distribution systems are used in 95 percent of all installations. Radio distribution means that only one end of the distribution power line is connected to a source. If the source end becomes open or de-energized, the entire feed area is de-energized, and all the customers on that feeder will be out of service. Exceptions include area networks – they are used in densely populated areas like downtown region of a city – and spot networks, typical of a high-rise building, or possibly a shopping mall. These networks represent very reliable type of designs, and because of the application, the expense is justified.

This slide should help reinforce our earlier discussion of the importance of understanding the power equation. Compare the conductor size on the low and the high-voltage sides of the transformer pictured on this slide. So for example, notice on the 13,200 volt side, you've got large aluminum conductors pictured, whereas on the 230,000 volt side, the conductors are much smaller. So just a further example, the higher the voltage, the smaller the conductor can be. Another thing represented by this particular slide is a reminder that multiple transmission lines are feeding a substation of this type. So if one line went down, power would still be provided to the substation. However, if one of the distribution, the radio lines were disconnected, customers on that line would lose power.

Uninsulated lines are used overhead to help dissipate heat and reduce weight. Uninsulated lines are less costly. This can represent a significant safety concern, however. Many electrical fatalities are caused by people inadvertently contacting uninsulated overhead power lines. Another aspect of overhead power lines is that many people consider these lines to be unsightly, and then further note the small insulators that are used here because the distribution voltages are much lower than the transmission level.

Aesthetically, most people prefer underground construction. The overall cost is anywhere from three to ten times that of overhead installations, reasons being that trenches must be dug, and insulated conductors have to be used. Underground lines are not exposed to wind, fallen tree branches and lightning, and therefore are typically much more reliable installations.

On this slide you'll see several types of protection equipment pictured, starting on the left-hand side with an overhead fuse. This is designed to interrupt the power flowing when excessive currents occur and provide equipment damage protection during a fault or a short-circuit. A line worker on patrol for an outage can normally see this fuse if it's been blown at a distance. The fuse link actually drops down from the housing.

On the right-hand side is a recloser, and a recloser exploits the fact that many disturbances are temporary, and so a recloser can be used as a circuit breaker on a distribution line. Reclosers typically are set to trip two to three times before a lockout condition occurs. In fact, a number of you may have experienced the operation of a recloser during a thunderstorm. You'll note that the lights briefly go out, come back on and may go out again, come back on. And then by the third time, if the short-circuit hasn't been cleared, the lights stay out or stay off. And then once it's locked out, a line worker has to manually reset the device. Underground lines are typically not automatically reclosed, and the reason for this is most underground faults result in significant damage, so they need to be immediately locked out.

We talked about the importance of transformers before. In this application, step-down transformers convert primary distribution voltages to secondary distribution levels suitable for the consumer. A residential, or kilowatt hour meter, measures the energy used by the consumer. Utilities connect their service wires to the consumer's service entrance equipment, or main disconnect panel. The National Electrical Code, or NEC, has very specific rules and regulations on how the service equipment must be designed and installed.

Next I'll outline some policy resources available for tribal utilities. The Federal Energy Regulatory Commission, or FERC, is the United States federal agency with jurisdiction over interstate electricity sales and wholesale electric rates. The North America Electric Reliability Corporation, or NERC, is a nonprofit corporation whose mission is to ensure the reliability of the North American bulk power system. NERC oversees eight regional reliability entities and encompasses all of the interconnected power systems of the contiguous United States, Canada, and a portion of Baja California and Mexico. Regional reliability councils include the Western Electricity Coordinating Council, or WECC, and the Southwest Power Pool, Inc.

In North America, the majority of electrical power generated is produced by investor-owned utilities. Utility commissions are to serve the public interest by regulating utilities so that the customers receive safe, reliable and reasonably priced services. There are many resources available for tribes considering utility ventures. For example, the Western Area Power Administration, or WAPA, manages the transmission network in the Western United States, including fulfilling requirements for open access, ensuring reliable operations and overseeing development of transmission infrastructure required for the integration of large-scale renewable energy projects. DOE and WAPA view tribes and stakeholders as playing a key role in the development of the future electricity system. There are currently eight tribal electric utilities and one natural gas utility. A handbook titled "Establishing a Tribal Utility Authority" written by Leonard Gold provides a guide to help interested parties evaluate the feasibility of forming a tribal utility.

Some resources you may find useful are provided on this slide. I described WAPA and the "Establishing a Tribal Utility Handbook" resources on the previous slide. So I just want to point out the Energy Information Administration is an excellent source of energy-related statistics and information. Under technology at the website link provided, OSHA gives detailed information where you can learn more about energy resources and equipment used in a typical power generation transmission and distribution system. Under Policy, information is available from the American Council for an Energy Efficient Economy, the Western Electricity Coordinating Council and the Intertribal Council on Utility Policy.

So thank you for your attention during this presentation. If you have questions or desire more details, my contact information is provided on this slide. Some other excellent sources of technical assistance are provided as well. So again, thank you.

Amy Hollander:
Thank you, Dr. Ammerman, for that overview of the electricity grid basics.

There are two series in the program: the Foundational courses and the Leadership, or Professional courses. The Foundational courses give basic information on renewable energy technologies, strategic energy planning and grid basics. The Leadership and Professional courses cover more detail on the components of the project development process and existing project financing structures. The Foundational courses are divided into Energy Basics and Renewable Energy Technologies. Energy Basics include assessing energy needs and resources based on a tribe's location and available resources. Electricity Grid Basics review the types of utility grids in the United States and resources of how tribes can tie into or be independent of existing power grids. Strategic Energy Planning teaches the steps to take when setting up renewables.

The Renewable Technology Webinars give basic information on the types of renewables that are successfully used in today's world. Be sure to visit the DOE Office of Indian Energy website to find these webinars and other tools.

And that concludes our webinar. Thank you for your attendance.

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