

Transcript Lesson 4c. Electricity

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Welcome to Module 4c, Electricity Delivery, part of the course Renewable Energy Integration in the Energy System, developed by The Hague University of Applied Sciences.

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In this module, we explore the two main technologies used to deliver electricity: the electric generator, which transforms mechanical motion into electricity, and the solar panel, which transforms sunlight into electricity. Before discussing these systems, we will review some key concepts about electrical energy that will help us understand how they work.

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To understand electricity, we start at the atomic level. Every material is made of atoms, which consist of a central nucleus containing protons and neutrons, with electrons moving around it in different energy levels.

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Electrons are negatively charged, while protons are positively charged. Normally, an atom is electrically neutral because it contains equal numbers of protons and electrons.

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The electrons most relevant to electricity are those in the outermost shell of the atom, called valence electrons. In conductors — materials like copper or aluminum — these outer electrons are loosely held and can move freely from one atom to another.

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When energy is applied to a conductor, for example by connecting it to a power source, these loosely bound electrons begin to drift from one atom to the next. This movement of electrons through a material is what we call electric current.

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Not all materials allow electrons to move freely. Conductors, such as copper, silver, and aluminum, allow current to flow easily. Insulators, such as plastic, glass, and air, resist the flow of electricity. This is why electrical wires are made of copper but wrapped in insulating material for safety.

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For current to flow, we need a closed circuit — a complete, unbroken loop. If the circuit is broken, the current stops. This is similar to water in a pipe: if the pipe is cut, the flow stops.

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There are two main types of electric current. Direct current, or DC, flows in one constant direction, as in batteries. Alternating current, or AC, periodically reverses direction and is used in power grids and homes.

Think of DC like water flowing steadily in one direction through a pipe — always the same way. AC, on the other hand, is like water being pushed back and forth in the pipe, reversing direction many times per second. Even though the water oscillates rather than flowing steadily in one direction, energy is still effectively transferred through the system.

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Ohm's Law describes the relationship between voltage, current, and resistance. Using the water analogy: voltage is like the pressure pushing the water; current is the amount of water flowing per second, and resistance is the narrowness of the pipe that restricts the flow. Mathematically, voltage equals current multiplied by resistance, or V equals I times R .

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Electrical power is the rate at which energy is delivered. It equals voltage multiplied by current, or P equals V times I . Together with Ohm's Law, these relationships fully describe how an electrical system behaves. Voltage tells us how strongly electrons are pushed, current tells us how many electrons are moving, resistance tells us how difficult it is for them to move, and power tells us how much energy is being transferred per second.

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Voltage is the electrical pressure that drives electric charges through a circuit — more precisely, the difference in electric potential between two points. In DC systems, typical voltages are around 5 volts for smartphones and 19 volts for laptops.

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AC systems operate at higher voltages. Homes in Europe typically use 230 volts. Local distribution lines carry several kilovolts, such as 10 or 20 kV, and long-distance transmission uses very high voltages of 110 kV, 220 kV, or 400 kV and above to minimize energy losses. In the traditional grid, electricity is produced in power plants, transmitted at high voltage, and then stepped down for delivery to homes.

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This traditional model is changing rapidly. As more homes install solar panels and other renewable energy systems, they are becoming energy producers as well as consumers, feeding electricity back into the grid at lower voltages.

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These voltage changes are made possible by transformers. A transformer changes the voltage of AC electricity using the principle of electromagnetic induction, discovered by Michael Faraday. It consists of two wire coils — a primary and a secondary — wrapped around a shared iron core. When alternating current flows through the primary coil, it creates a changing magnetic field, which in turn induces a voltage in the secondary coil. Energy is thus transferred without any direct electrical connection.

The voltage ratio between the two coils depends on their number of turns. If the secondary coil has more turns, voltage increases — a step-up transformer. If it has fewer turns, voltage decreases — a step-down transformer. As voltage changes, current changes inversely, keeping total power approximately constant.

Importantly, transformers only work with AC. DC current does not produce a changing magnetic field, so no energy transfer occurs.

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For DC systems, voltage conversion is done by DC-to-DC converters. A step-down, or buck, converter reduces voltage — for example from 12 volts to 5 volts. A step-up, or boost, converter increases voltage — for example from 3 volts to 5 volts. Inside, the converter rapidly switches the current and uses coils and capacitors to control the output. This is essential in devices like smartphones, where the battery provides around 3.7 volts but different components require different voltages.

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When a system needs to convert between AC and DC — or vice versa — while also changing the voltage level, different converter types are used. A smartphone charger, for example, converts 230 volt AC from the wall to 5 volt DC for the phone. A solar inverter does the opposite, converting 48 volt DC from the panels to 230 volt AC for the home grid.

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Most long-distance electricity transmission has historically used AC, because transformers — a simple and efficient technology — make it easy to raise voltage and thereby reduce transmission losses. However, advances in AC-to-DC converters have made High Voltage Direct Current, or HVDC, increasingly viable. HVDC transmission can carry electricity over long distances with even lower losses than high-voltage AC, and is now used for major international grid connections.

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An electric generator converts mechanical energy into electrical energy. Generators are used in many types of power plants: in thermal plants — coal, gas, or nuclear — heat produces steam that spins a turbine connected to the generator. In hydroelectric plants, flowing water turns a turbine. In wind turbines, the wind spins a rotor that drives a generator.

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A DC generator produces current flowing in one constant direction by using a commutator — a rotating switch that reverses the coil connection every half turn, ensuring a steady output. An AC generator, also called an alternator, uses slip rings instead, which allow the current to alternate naturally. This simpler design makes AC generators more common in large-scale power generation.

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An electric motor does the reverse of a generator: it converts electrical energy into mechanical motion. When current flows through a coil placed in a magnetic field, a force is exerted on the coil, causing it to rotate. By continuously switching the current direction at the right moments, the motor maintains continuous rotation.

DC motors use a commutator to manage current switching and offer straightforward speed control, making them suitable for small devices and battery-powered applications. AC motors rely on a rotating magnetic field from the alternating current to drive the rotor. With fewer moving electrical contacts, they are more robust and require less maintenance, making them the preferred choice for industrial applications.

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Electric motors offer several important advantages. They are highly efficient compared to combustion engines, converting most input energy into useful mechanical work. They deliver instant torque, operate quietly, produce no direct emissions, and can be precisely controlled in speed and position. These qualities make them essential in applications ranging from household appliances to robotics.

On the downside, electric motors depend on a reliable power source. In mobile applications, this typically means batteries, which add weight, cost, and limited range. Some motor types — particularly brush-based DC motors — require maintenance due to wear. High upfront costs and sensitivity to temperature extremes are additional considerations.

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A photovoltaic, or PV, solar panel converts sunlight directly into electricity. Solar panels are used in a wide range of applications, from rooftop installations on homes and buildings to large solar farms that supply electricity at the grid scale.

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Global installed PV capacity has grown rapidly, driven by dramatic cost reductions, technological improvements, supportive government policies, and the growing demand for clean energy. In many parts of the world, solar energy is now among the cheapest sources of electricity.

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Solar panels work through the photovoltaic effect. When sunlight hits a solar cell — typically made of silicon — photons transfer energy to electrons, knocking them free. A p-n junction inside the cell, formed by combining n-type silicon, which has extra electrons, and p-type silicon, which has fewer electrons, creates an internal electric field. This field directs the freed electrons in one direction, generating a direct current.

The DC electricity produced is typically sent to an inverter, which converts it to AC for use in homes and the grid. Individual cells are connected to form panels, and panels can be combined into larger arrays.

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The main advantages of PV panels are that they generate electricity from a free and renewable energy source, have no moving parts and therefore require little maintenance, and can be deployed at many scales — from a single rooftop to a large utility farm. They also reduce electricity bills and increase energy independence.

The main disadvantages are intermittency — panels generate no power at night and less on cloudy days — which often requires battery storage or grid backup. Installation costs, though declining, remain significant. Efficiency is limited, and large installations require considerable space. The environmental impact of manufacturing and end-of-life disposal of panels is also a consideration.

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If you would like to explore any of the topics covered in this lesson in more depth, this slide provides a selection of videos that go further into each of the technologies presented.

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These are the references used in this lesson. Additional references are included on the individual slides.

Thank you for your attention, and see you in the next module.