Wind Energy Design and Fundamentals

An Online Continuing Education Course for Engineers

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Wind Energy Design and Fundamentals

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The rising concerns over climate change, environmental pollution, and energy security have seen increased interest in developing renewable energy, with wind energy being at the forefront. Wind energy refers to technology that converts the air's motion into mechanical energy, usually for electricity production.

Wind energy captures the natural air in our environment and converts the air's motion into mechanical energy. Wind is caused by differences in atmospheric pressure. Wind speeds vary based on geography, topography, and season. As a result, there are some locations better suited for wind energy generation than others. In general, wind speeds are higher near the coast and offshore since there are fewer objects like vegetation, mountains, and buildings to slow them down.

The mechanism used to convert air motion into electricity is referred to as a turbine, which is a large structure with several spinning blades. These blades are connected to a rotor, and an electromagnetic generator generates electricity when the wind causes the blades to spin. Traditionally, this energy was used for milling grain and pumping water, but today it is used to create electricity.

A major advantage of wind is that it is a clean and renewable form of energy. Its production of electricity has no direct carbon emissions or air pollutants and does not consume water. Wind also has relatively low operations and maintenance costs after initial construction. However, wind energy also faces several challenges. Wind speeds can vary throughout the day and year, causing intermittency issues for power grids. The price tag of wind power has traditionally been higher than conventional electricity generation sources, though the wind cost curve has declined significantly in recent years. Other concerns such as land use, noise, and bird disruption have also been raised.

In terms of technology, turbine design focuses on optimizing power output by focusing on two key parameters: blade length and average wind speed. The latter is affected by surface terrain and varies spatially, directionally, and seasonally. The effectiveness of a particular installation is quantified by the "capacity factor"—the ratio of actual annual energy output to the theoretical maximum output. Several basic designs are in use, but most commercial installations use a

horizontal axis, upwind-facing design. Wind energy is expanding both onshore and offshore with bigger turbines—bigger in both physical size and generating capacity—to capture more stable winds and to maximize return on installation costs.

The purpose of this course is to introduce the general aspects of wind energy and wind turbines. The course discusses the wind turbine's operating principles, the key components, technology & performance features, cost economics, and various environmental and social aspects.

Learning Objectives:

- Basic concepts of wind energy: source, site, measurement
- Factors influencing wind energy production
- Types of wind turbines—horizontal and vertical axis, onshore, and offshore configurations
- The key components of wind turbine and their functions - selection and specifications of rotor blades, gearbox, tower, etc.
- Theoretical, practical, and net energy output from wind turbine
- Energy calculations, limits on the efficiency and coefficient of performance of a turbine
- Wind turbine design parameters—power curve, TSR, number of blades, etc.
- Onshore and offshore wind farms—pros and cons
- Site analysis and selection—Weibull curve
- Economics of Wind Energy: the levelized cost of energy
- Control schemes of wind turbines
- Environmental and social aspects of wind turbines

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1 Chapter 1: Fundamentals of Wind Energy

Wind is one of the most important sources of green and renewable energy.

Both the terms "wind energy" and "wind power" refer to the process of using the wind to generate mechanical or electrical power. This mechanical power can be used for specialized tasks like grinding grain or pumping water, or it can be converted to electricity using a generator.

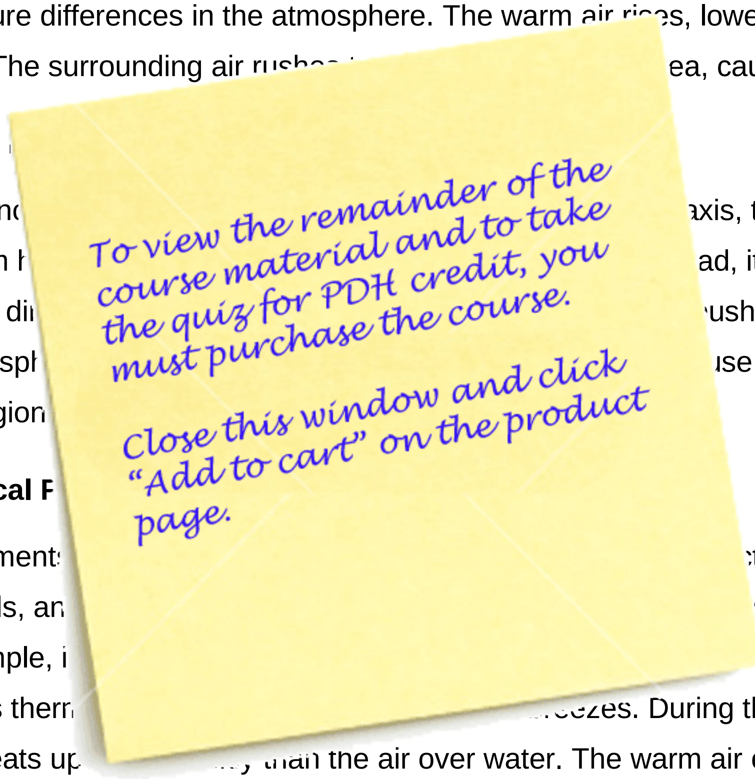
1.1 Wind

Wind is the movement of air caused by pressure variations in the atmosphere. Meteorologists call this wind-causing force the "pressure gradient force." The bigger the pressure gradient force (also known as the pressure differential), the faster and more powerful the wind generation. The pressure differential is the result of three concurrent events:

a. The sun unevenly heating the atmosphere
b. The rotation of the earth
c. Geographical features

1.1.1 Sun's Energy

The sun's energy heats the atmosphere and the Earth in an unequal manner. The sun's energy creates temperature differences in the atmosphere. The warm air rises, lowering atmospheric pressure locally. The surrounding air rushes … ea, causing wind to blow.



1.1.2 Rotation of …

The wind is influenc… axis, the air does not travel directly from h… ad, it is deflected by the Coriolis force; the di… ushed to the west in the northern hemisph… use of the Coriolis force, different region…

1.1.3 Geographical F…

Geographical element… t. Trees, buildings, lakes, the sea, hills, an… wind on the Earth's surface. For example, i… the temperature difference creates therm… eezes. During the day, the air above the land heats up … than the air over water. The warm air over the land