Electric Power Generation: From Renewable Energy Sources EEE210

Francis Ting

Xi'an Jiaotong-Liverpool University

Email: toting@xjtlu.edu.cn
Room: EE324

March 19, 2018

Overview

1. Introduction
2. Hydroelectric Power Plants
3. Solar Power
4. Wind Power Plants
5. Geothermal Power
6. Biomass Power Plants

Table of Contents

1. Introduction
2. Hydroelectric Power Plants
3. Solar Power
4. Wind Power Plants
5. Geothermal Power
6. Biomass Power Plants

Alternatives to fossil fuels are solar power, wind power, geothermal, biomass, and tidal power.

These sources have the capability to produce sustainable energy with zero pollutant and greenhouse gases.

Water has been the most widely used form of renewable energy source for the production of electricity.

Relevant power plants that use renewable energy sources are described in the following slides.

Table of Contents

1 Introduction

2 Hydroelectric Power Plants

3 Solar Power

4 Wind Power Plants

5 Geothermal Power

6 Biomass Power Plants

Hydropower is considered to be renewable energy source because it uses the continuous flow of water without using up the water resources.

In the U.S., it was accounted for 63% of all renewable energy sources in 2009.

Almost all suitable sites for dams have already been developed, so not much further growth in hydroelectric plant.

However, there are rooms for improvement in terms of efficiency and reliability, in order to decrease the maintenance cost.

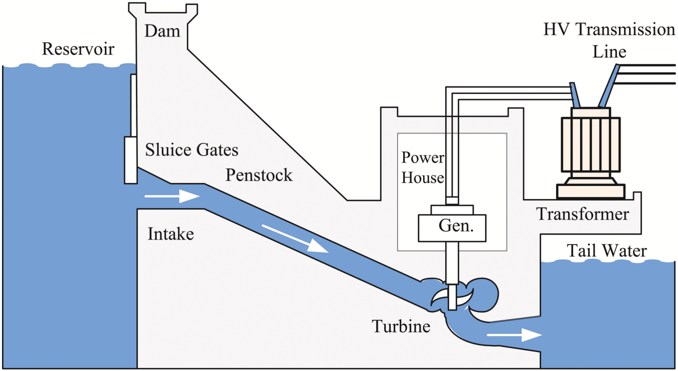

Figure 1: Schematic diagram of a hydroelectric power plant

The operation of hydroelectric power plant, depicted in Figure 1 can be described in the following process:

1. The water from the dam is led to the water turbine through the penstock.
2. Concurrently, potential energy of the elevated water is transformed into kinetic energy and turns the water turbine.
3. The water turbine converts hydraulic energy into mechanical energy.
4. The generator then converts this mechanical energy into electrical energy.

The hydraulic generators are usually salient-type rotor with many poles. To maintain the generator voltage frequency constant, the turbine must spin the generator at a constant speed given by

$$n = \frac{120f}{p} \tag{1}$$

where
f is the generated voltage frequency, and
p is the number of poles of the generator.

They hydro power P_w is calculated via

$$P_w = q\rho g h \text{ W} \tag{2}$$

where

q = rate of flow of water in m^3/s
ρ = density of water $\approx 1000 \text{ kg/m}^3$
g = acceleration of gravity $= 9.81 \text{ m/s}^2$
h = effective head of water in m

Further substitution of constants ρ and g yields the available hydro power P as

$$P = 9.81qh \text{ kW} \tag{3}$$

Taking into account the overall efficiency of the hydropower plant, the electrical power output in kW is

$$P = 9.81qh\eta \text{ kW} \tag{4}$$

where $\eta = \eta_p \eta_t \eta_g$,
$\eta_p =$ penstock efficiency,
$\eta_t =$ turbine efficiency, and
$\eta_g =$ generator efficiency.

Tutorial

Example (Example)

A large hydroelectric power plant has a head of 116 m and an average flow of 3100 m^3/s. Assume the following efficiencies:

1. penstock efficiency η_p=97%,
2. turbine efficiency η_t=77%, and
3. generator efficiency η_g=95%.

(a) Calculate the generated electric power.

(b) Calculate the annual energy produced.

Tutorial: Write down your solution here

Run-of-the river power plants

Hydroelectric plants with no reservoir capacity are called run-of-the-river plants.

These plants use the natural flow of rivers to capture the kinetic energy carried by water.

Drawback: Significant fluctuations in power output throughout the year.

Advantage: Cheap and has very little environmental impact.

Pumped-storage hydro power plants

A means of saving surplus electricity during off-peak times as the potential energy of the elevated water.

A typical pumped storage consists of two water reservoirs located at two different elevations.

When electric demand is low, the synchronous machine operates as motor (powered by the grid).

When electric demand is high, water is released back into lower reservoir through the turbine to generate power to supply the grid.

Table of Contents

1. Introduction
2. Hydroelectric Power Plants
3. Solar Power
4. Wind Power Plants
5. Geothermal Power
6. Biomass Power Plants

Solar power utilizes the abundant sunlight as the source. It has the potential to meet a significant portion of the future energy demands in a clean and cost-effective manner.

Solar energy can be converted directly into electricity by photovoltaic (PV), via the semiconductor materials in solar panels.

A more economical method is to use concentrating solar power (CSP) technologies.

CSP technologies use mirrors to reflect and concentrate sunlight onto receivers that heat a working fluid to high temperatures. It then turns the steam turbine, driving a generator.

The three types of CSPs:

1. parabolic troughs
2. parabolic dishes, and
3. central receivers.

Tracking techniques are required to ensure the maximum amount of sunlight enters the concentrated system.

Parabolic Troughs

A parabolic troughs consists of many long parallel rows of curved mirrors that concentrate light onto a receiver, see Figure 2

The troughs follow the trajectory of the sun by rotating along their axis to ensure the maximum amount of sunlight.

The concentrated solar radiation heats up a fluid circulating in the pipes to temperatures of up to 750°F.

The hot oil is pumped to heat exchangers to generate steam, which is used to drive a conventional steam turbine generator.

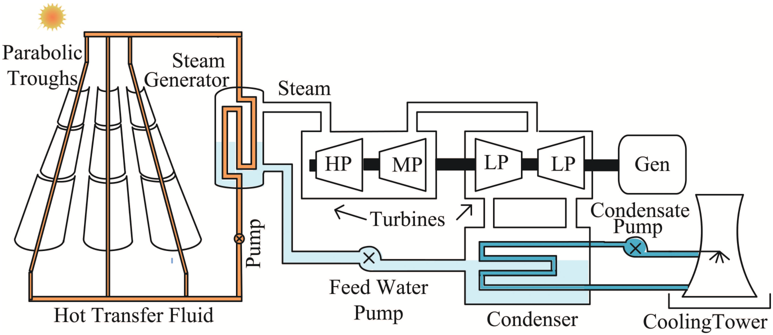

Figure 2: Solar power plant with parabolic trough concentrator

Parabolic dish concentrators (dish stirling)

A parabolic dish concentrator reflects solar radiation onto a receiver located at the focal point of the dish.

The solar dish concentration ratio is much higher than the solar trough, typically over 2000, with a working fluid temperature to over 1300°F.

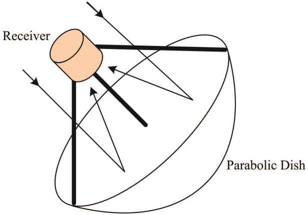

Figure 3: Schematic of a parabolic dish concentrator

Solar Tower

This system consists of a field of thousands of flat mirrors, called *heliostats*, shown in Figure 4.

The computer controlled mirrors track the sun and reflect the sunlight onto a central receiver mounted on the top of a tower.

A working fluid (synthetic oil or molten salt) circulates in the receiver, heated over 1300°F (704.44°C).

The heated fluid is pumped to heat exchangers to generate steam and drive a conventional steam turbine generator, located at the foot of the tower.

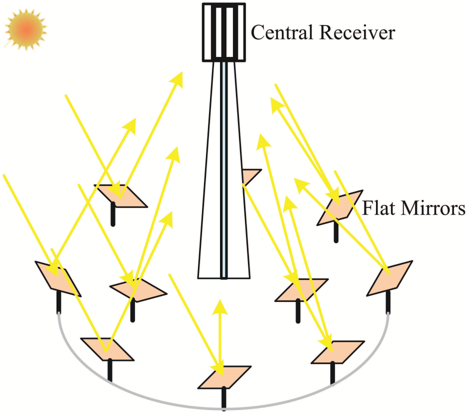

Figure 4: Solar tower

Photovoltaic Electric Power Plants

- Photovoltaic technology is the process that converts sunlight directly into electricity using semiconductor materials.
- To give desired electrical power output, a number of panels are connected together to form a PV array.
- With governments offering several tax incentives for non-polluting power, solar energy is becoming a more economic viable option.
- PV power plants are getting popular: Spain (33 plants), Germany (8 plants), and Portugal (2 plants).
- The largest PV power plant (600 MW), called *Rancho Cielo,* is under development in Mexico.

Table of Contents

1 Introduction

2 Hydroelectric Power Plants

3 Solar Power

4 Wind Power Plants

5 Geothermal Power

6 Biomass Power Plants

Wind Power Plants

- In ancient time, people harnessed wind energy to pump water or grind grain.
- Similar to solar power, wind is intermittent and is highly dependent upon weather and location.
- As solar power and wind power complement each other, a hybrid solar-wind power system may be used for generation.
- The hybrid system is viable alternative to fossil fuels.
- Two types of wind turbines:
  1. Fixed-speed wind turbine
  2. Variable-speed wind turbine

Wind Power

The power extracted from wind is

$$P = \frac{\pi}{8} C_p \rho D^2 v^3 \quad \mathrm{W} \tag{5}$$

whereby

C_p is the power coefficient

ρ is the air density

D is the rotor diameter in meter

v is the wind velocity (wind speed)

Wind Power

Considering the mechanical losses of the gearbox, turbine blades, and the losses in the generator, and the inclusion of the corresponding efficiencies $(\eta_{gb}, \eta_b, \eta_g)$, the net output power becomes

$$P = (\eta_{gb}\eta_b\eta_g)\frac{\pi}{8}C_p\rho D^2 v^3 \quad \mathrm{W} \tag{6}$$

Tutorial

Examples

A very large horizontal wind turbine is mounted with its hub at 135 m and has a rotor diameter of 126 m. The turbine operates in an area with an average wind velocity of 12.5 m/s at 135 m altitude and an air density of 1.18 at 70° F. The turbine power coefficient is 0.46. The generator is directly coupled to the turbine without a gearbox. Assume the following efficiency, $\eta_b = 94.6\%$, and generator efficiency, $\eta_g = 96\%$ percent. Determine the power output.

Tutorial: Write down your solution here

Table of Contents

1 Introduction

2 Hydroelectric Power Plants

3 Solar Power

4 Wind Power Plants

5 Geothermal Power

6 Biomass Power Plants

Geothermal Power

- Geothermal energy is derived from heat within the earth, usually in the form of underground steam or hot water.
- The sources of geothermal energy are due to the molten rocks that are found beneath the surface of the earth known as *magma*.
- When the rising hot water and steam is trapped in permeable rocks under a layer of impermeable rocks, geothermal reservoirs are formed.
- Geothermal energy is considered renewable energy source because heat is continuously produced inside the earth.
- Three types of geothermal power plants: dry-steam, flash-steam, and binary-cycle.

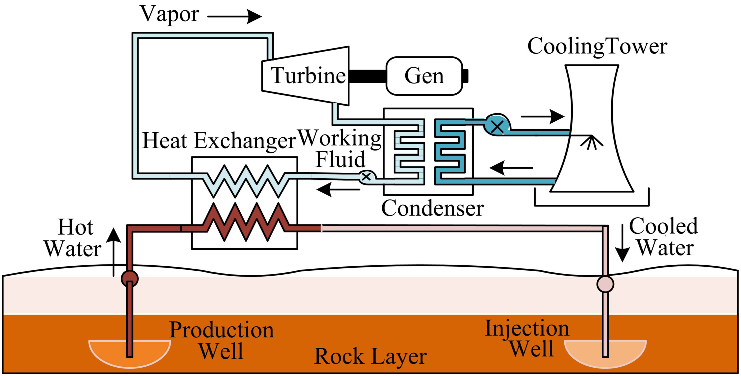

Figure 5: Schematic of a binary-cycle power plant

Table of Contents

1. Introduction
2. Hydroelectric Power Plants
3. Solar Power
4. Wind Power Plants
5. Geothermal Power
6. Biomass Power Plants

Biomass Power Plants

- Biomass is renewable organic material which contains stored energy from the sun.
- There is a wide variety of biomass energy resources, including wood, plants, agricultural residues, and aquatic vegetation, municipal, and animal wastes.
- Biomass power plants use direct combustion, operating on a conventional steam-cycle. In this process, biomass is burned in a boiler to produce steam.
- The steam then turns a turbine, which is connected to a generator that produces electricity.

The End