Steam Turbine Power Plant

According to Wiser, steam turbine power plants generate approximately 90% of the electricity produced in the United States [114]. Power plants that use a steam turbine to produce electricity are categorized according to the source and use of the steam. Nuclear, coal, combined cycle, cogeneration, and some solar power plants use steam cycles in order to produce power.

Monticello Nuclear power plant [29].

Steam Cycle

A steam cycle power plant is operated using the Rankine cycle. Water enters a boiler where it is heated to create steam. The steam is then sent through a steam turbine that rotates the shaft of a generator to create electricity. The steam exits the turbine into a condenser, which converts the steam back into saturated water. The saturated water is then pumped back into the boiler to repeat the process.

Monticello nuclear generating plant turbine deck [29].

It may seem strange that in the Rankine cycle the steam is first cooled down so that it condenses into liquid water and then is heated back up to create steam. This is done because liquid requires much less energy to move than vapor. Because pumps are much more efficient than compressors, the energy consumed by a pump to move the liquid water is negligible compared to the overall amount of energy produced by the system.

There are many extra components that are added to the basic system which are used to improve the cycle's efficiency. Some of these components include: reheaters, moisture separators, and feedwater heaters. With reheaters, the steam coming out of the high pressure turbine is rerouted back to the boiler to be heated again before being routed through subsequent lower pressure turbines. This requires a minimal amount of additional heat while providing extra power through the low pressure turbines. Water droplets in the steam can cause damage to the turbine blades. Moisture separators take the wet steam and, as it passes through, filter out the water droplets so that dry steam comes out. Feedwater heaters are essentially heat exchangers and it comes in a couple main designs, open and closed. A portion of the steam is taken after the high pressure turbine and routed to the feedwater heater where it is used to heat the post-condenser water stream before it is sent to the boiler. This reduces the amount of heat needed from the boiler to produce the required temperature and pressure of the steam going to the turbines

Boiler Fuel

There are several different types of fuel that can be used for the boilers in a steam system. The three main fuel sources that are currently used are: fossil fuels (coal, oil, and natural gas), nuclear, and solar. Each operates somewhat differently, but they all serve the same purpose.

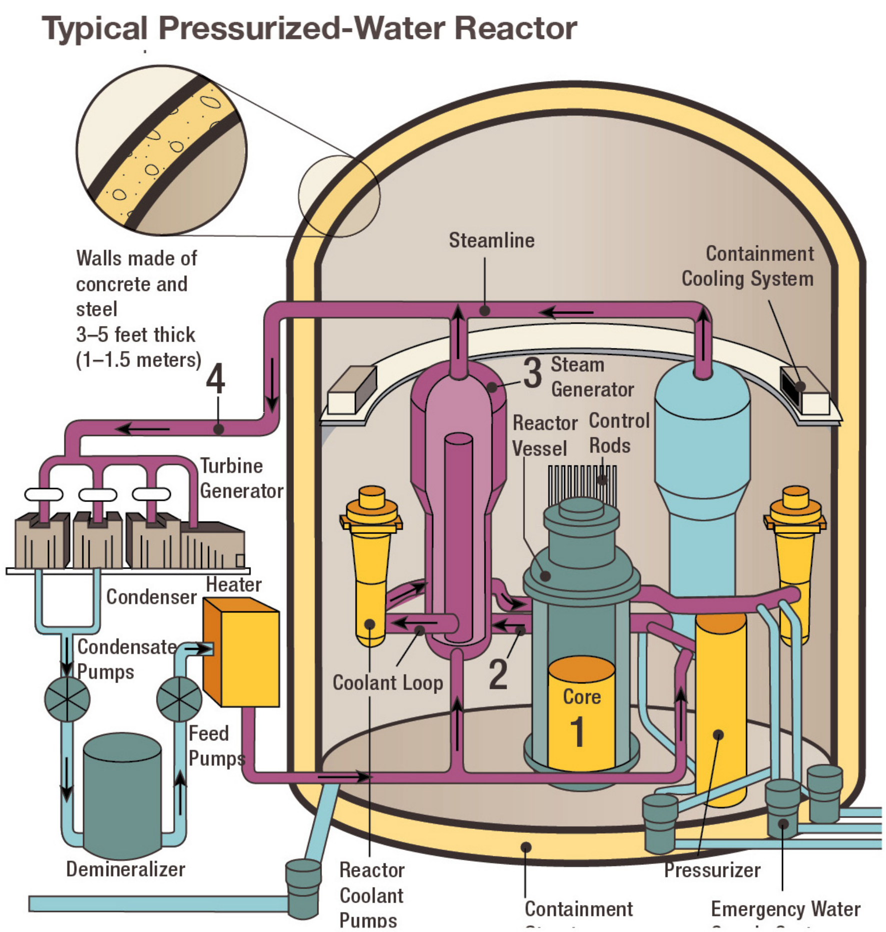
Coal

Coal is the most commonly used fuel for steam generation boilers, but other fossil fuel boilers are also used. This is due to the fact that it produces steady and reliable energy at a relatively low price. There are still large deposits of coal in many parts of the world, and it can be transported easily by trains and barges around the world. When coal is delivered to a plant, it is stored in the main yard. Excess coal is also stored in case of emergency outages or for times of high electricity demand. The coal is sent through a crusher where it is pulverized into a fine powder. The coal powder is then mixed with hot air and pumped into the boiler to fuel the combustion reaction. The combustion reaction produces the energy needed for the boiler to heat the water in the pipes into superheated steam.

Nuclear

Nuclear power plants use several different types of reactor designs in order to provide heat input to a Rankine cycle. The two most commonly used reactor designs used in the United States are the Boiling Water Reactor (BWR) and the Pressurized Water Reactor (PWR).

In a BWR, nuclear fission within fuel rods generates heat used to boil feedwater and create superheated steam that is sent through a steam turbine. Since the water is cycled through the nuclear reactor and picks up some radioactive isotopes, radiation protection is required for the equipment and components such as the turbine and condense.



Typical pressurized water reactor [29].

Like a BWR, a PWR uses nuclear fission to create heat that is used to raise the temperature of a water loop. The water loop is kept at a very high pressure so that it can be heated to high temperatures without boiling. The pressurized water is then run through a heat exchanger where it heats a second water loop. This second loop is not pressurized to as high a pressure so that it turns into superheated steam.

Several other types of nuclear reactors, including Gas-Cooled Reactors, Pressurized Heavy Water Reactors, Fast Neutron Reactors, and Light Water Graphite Reactors, are used primarily in other countries or under development.

Solar

Solar power has a very large potential for energy production. In recent years, researchers have been perfecting methods for converting solar energy into electricity. There are a couple of different ways to harness the sun's energy to produce steam, and thus electricity.

One method to produce steam using solar power is by concentrating sunlight with parabolic mirrors. The parabolic mirrors reflect the sun's rays upon a tube containing fluid that absorbs the heat from the concentrated rays. The heated fluid is then pumped through a heat exchanger, heating water to produce steam.

Mirrors powering the PS10 solar boiler in Spain [31].

A second way to produce steam using solar power is by installing a group of mirrors around a tower that functions as a central receiver. The mirrors direct and concentrate the sun's energy to the receiver in order to heat a fluid in order to store and transfer the energy to then heat water to produce steam.

Feedwater System

Feedwater is water that is circulated through the steam cycle as it comes out of the condenser and is sent into the boiler. Feedwater heaters are used preheat the water in order to decrease the heating time in the boiler and increase the plant's overall efficiency. In large power plants, the water that exits the condenser is sent through a series of feedwater heaters. The tanks are heated by steam from the turbine. Each stage of the heating process in the turbine produces steam of a specific temperature that is used to preheat the feedwater for that stage. The feedwater heater closest to the boiler receives steam from the high-pressure turbine.

Efficiency

The efficiency of the simple steam cycle is generally lower than for other cycles such as the combined cycle. This is mainly due to the fact that not all the heat can be harnessed or completely used after the steam is sent through the steam turbines. This loss is dictated by the laws of thermodynamics and limits the efficiency of the system. The efficiency is set, in part, by the maximum temperature that the steam attains and the minimum temperature that can be used to cool the steam in the condenser.

The main source of the heat rejection occurs in the condenser where the excess thermal energy is discharged to the environment in the form of heat. In order to attain the required amount of power from the system, the turbines and the steam temperatures and pressure must be properly designed in order to work together properly and efficiently. However, there is still extra thermal energy in the liquid-vapor mixture at the exhaust of the low pressure turbines that is not useable due to the moisture content that would damage any more turbines without being reheated significantly. Carnot's theorem also shows that there is some inefficiency in the turbines which is based off of the ratio of cold to hot temperatures in the cycle. This ratio is why there are always inefficiencies in a system. This inefficiency in a steam turbine comes in the form of the extra steam at the turbine exhaust.

The efficiency of the steam turbine power plant depends on the type of fuel used in the boiler. The efficiency of coal-powered plants ranges from 32–42% depending on the pressure and temperature of the steam [44]. The efficiency of advanced coal generation plants, however, can approach 50% [44]. Nuclear generating plants with PWR and BWR reactors usually average 30–35% efficiency [44]. Nuclear generating plants have the capacity to achieve even higher efficiency levels, but are limited by the maximum temperatures allowed in the core, thus limiting efficiency. Efficiencies of solar boilers are harder to judge due to inconsistent weather. However, annual solar-to-electricity efficiencies of nearly 29% have been noted in some cases such as at the Ivanpah Solar Electric Generating Station in California as noted by the National Renewable Energy Laboratories [45].

Outages

Planned outages are a time where the power plant is shut down in order to check, repair, and replace equipment. During outages at nuclear power plants, for example, operators can replace used fuel assemblies. They must inspect specific parts of each component in a power plant before restarting the plant operations. Outages are usually scheduled in the spring or fall when electrical demand is the lowest.

The casing of a multistage turbine must be removed in order to inspect each turbine blade for possible corrosion, erosion, and cracks. Methods of turbine blade inspection include visual, magnetic particle, and sometimes ultrasonic inspections. To conduct a magnetic particle inspection, engineers magnetize the turbine and spray on a solution to reveal microscopic cracks, metal fatigue, or any other damage to the blades. Ultrasonic inspections are less common; they are conducted mainly to ensure that the rotor shaft is internally intact.

The boiler also needs mandatory maintenance. In nuclear facilities, regular inspections take place to ensure smooth and safe operation of the reactor. The reliability of each safety feature must be tested to ensure proper functioning in case of an emergency. In coal boilers, fly ash can adhere to pipe walls. This decreases the heat transfer that is occurring in the pipes which lowers the efficiency and possibly damages the boiler.

Maintenance of the steam turbine at Faribault Energy Park [130].

Feedwater systems can be inspected and worked on while the plant is in operation; this allows for the plant to maintain a high running time. They inspect the system by closing the valves of the pipes that transfer the steam from the turbine to the particular tank they are examining.

Water entering the steam cycle needs to be properly treated. Increased erosion on all equipment will occur if the chemicals and impurities in the makeup water are not treated. The make-up water can be tested through a lab analysis or excess erosion can be noted during component inspections. The water must be properly treated to prevent damage to the equipment.

Locations

Faribault Energy Park
Monticello Nuclear Generating Station

Minnesota State University, Mankato

Components

Components on Engaged that are included in Steam Turbine Power Plants:
Steam Turbine
Boiler
Cooling Tower