FOSSIL FUEL POWER PLANT

A fossil fuel power plant (FFPP) (also known as steam electric power plant in the US [[1]], thermal power plant in Asia [[2]], or power station in the United Kingdom (UK) [[3]] is an energy conversion center designed on a large scale for continuous operation. Just as a battery converts relatively small amounts of chemical energy into electricity for temporary or intermittent use, the FFPP converts the energy stored infossil fuels such as coal, oil, or natural gas successively into thermal energy, mechanical energy, and finally electric energy for continuous use and distribution across a wide geographic area. Each FFPP is a highly complex, custom-designed system. Present construction costs (as of 2004) run to $1300/kW, or $650 million USD for a 500 MWe unit. Multiple generating units may be built at a single site for more efficient use of land, resources, and labor. The operational descriptions below are typical for a large plant and will vary from one plant to the next.

Fuel transport and delivery

Coal may be delivered by transport truck or railroad cars. A large coal train may be nearly a mile long, containing 100 cars, each with 100 tons of coal, for a total load of 10,000 tons. Modern unloaders use rotary dump devices. The unloader includes a train positioner arm that moves the entire train to position a car over a coal hopper. The dumper clamps an individual car against a platform, which swivels the car upside down to dump the coal. Swiveling couplers enable the entire operation to occur while the cars are still coupled together. Unloading a train takes about three hours. Older unloaders may still use bottom dump rail cars. Generating stations adjacent to a mine sometimes haul coal with massive diesel-electric drive trucks with 140 ton capacity. Trucks this large typically have 8 ft (2.5 m) diameter tires, too big and heavy to be licensed for highway use.

For startup or auxiliary purposes, the plant may use no. 2 or no. 5 fuel oil as well, Fuel oil may be delivered by tanker truck or train car. It is stored in vertical cylindrical steel tanks as large as 90,000 barrels (14,000 m3). The heavier no. 5 "bunker" fuel must be steam heated before pumping in cold climates.

Natural-gas fuelled plants are usually built adjacent to gas transport pipelines or have dedicated gas pipelines extended to them.

Fuel processing

Coal is prepared for use by crushing the rough coal to pieces less than 2 inches (50 mm) size. The coal is transported from the storage yard to in-plant storage silos by rubberized conveyer belts at rates up to 4000 tons per hour. A 400 ton silo may feed a coal pulverizer (coal mill) at a rate of up to 60 tons per hour. It is introduced into the top of the pulverizer which grinds the coal to a powder the consistency of face powder and blows powder mixed with air into the furnace. A 500 MWe plant will have six such pulverizers, five of which can supply coal to the furnace at 250 tons per hour under full load.

Feedwater heating

The water used in the steam boiler is a means of transferring heat energy from the burning fuel to the mechanical energy of the spinning turbine. Because the metallic materials it contacts are subject to corrosionat high temperatures and pressures, the water is highly purified before use. A system of water softeners andion exhange demineralizers produces water so pure that it coincidentally becomes an electrical insulator, withconductivity in the range of 0.3–1.0 microsiemens per centimeter. The purified water known as makeup wateris added to the feedwater at perhaps 20 US gallons per minute (1 L/s) to make up for the small losses due to steam leaks in the system.

The feedwater cycle begins with condensate water being pumped out of the condenser after travelling through the steam turbines. The flow rate at full load in a 500 MWe plant is about 6000 US gallons per minute (0.4 m^3/s). The water flows through a series of six or seven intermediate feedwater heaters, heated up at each point with steam extracted from an appropriate duct on the turbines and gaining temperature at each stage. Typically the fourth heater is a deaerator, which removes dissolved air from the water, further purifying and reducing its corrosivity. The water may be treated following this point with hydrazine, a chemical which removes the last remaining oxygen in the water to below 5 parts per billion (ppb). It is also treated with pHcontrol agents such as ammonia or morpholine to keep the residual acidity low and thus non-corrosive.

Boiler operation

The boiler is a rectangular furnace about 50 ft (15 m) on a side and 130 ft (40 m) tall. Its walls are made of a web of high pressure steel tubes about 2.3 inches (60 mm) in diameter.

Coal is blown into the furnace from fuel nozzles at the four corners and it rapidly combusts, forming a large fireball at the center. This heats the water that circulates through the boiler tubes. The circulation rate in the boiler is three to four times the throughput, typically driven by four massive sealed pumps. As the water in theboiler circulates it absorbs heat and changes to steam at 700 °F (370 °C) and 3200 lbf/in^2 (22.1 MPa), which is separated from the water by parallel plates inside a drum at the top of the furnace. The saturated (wet) steam is introduced into superheat pendant tubes hanging in the hottest part of the combustion gasses as they exit the furnace. Here the steam is superheated to 1000 °F (540 °C) to prepare it for the turbine.

Plants designed for lignite (brown coal) are increasingly used in locations as varied as Germany, Victoria, Australia, and the midwestern US. Lignite is a much younger form of coal than black coal. It has a lower energy density than black coal and requires a much larger furnace for equivalent heat output. Such coals can be up to 70% water and ash, yielding lower furnace temperatures and requiring larger induced draft fans. The firing systems also differ from black coal, and typically draw hot gas from furnace exit level and mix it with the coal in fan-type mills that exhaust the pulverised coal/hot gas mix into the boiler.

Steam turbine generator

The turbine generator consists of a series of steam turbines interconnected to each other and a generator on a common shaft. There is a high pressure (hp) turbine at one end, followed by an intermediate pressure (ip) turbine, two low pressure (lp) turbines, and the generator. As steam moves through the system and drops in pressure, it expands in volume, requiring larger diameter and longer blades in each succeeding turbine to extract the remaining energy. The entire rotating mass may be over 200 tons and 100 ft (30 m) long. It is so heavy that it must be kept turning slowly even when shut down (3 rpm) so that the shaft will not sag even slightly and become unbalanced. This is so important that it is one of just four functions of blackout emergency power batteries on site: emergency lighting, communication, station alarms, and turbine generator turning gear.

In operation, the superheated steam from the boiler passes through 14–16 in (350–400 mm) diameter piping down to the hp turbine, where it falls in pressure to 600 lbf/in³ (4 MPa) and 600 °F (315 °C), exits through 24–26 in (600–650 mm) diameter cold reheat lines and passes back up into the boiler where the steam is reheated in special reheat pendant tubes back to 1000 °F (540 °C). The hot reheat steam is conducted down to the ip turbine where it falls again in both temperature and pressure, and exits directly to the large bladed lp turbines, and finally enters the condenser.

The generator, 30 ft (9 m) long and 12 ft (3.7 m) diameter contains a stationary stator and a spinning rotor, each containing miles of heavy copper conductor— no permanent magnets here. In operation it generates up to 21,000 amps at 24,000 volts AC (504 MWe), as it spins at 3600 rpm, synchronized to the 60 Hz power grid. (The power grid frequency is 60 Hz across the United States and Canada, typically 50 Hz in Europe and parts of Japan.) This electricity flows to a distribution yard, where transformers step the voltage up to 115, 230, 500, or 765 kV AC as needed for transmission to its destination. The rotor spins in a sealed chamber cooled withhydrogen gas, selected because it has the highest known heat transfer coefficient of any gas. This system requires special handling during startup, with air in the chamber displaced by carbon dioxide first, before filling with hydrogen. This ensures that the highly flammable hydrogen will not mix with oxygen in the air.

Steam condensing

The exhausted steam exiting the low pressure turbines contacts condenser tube bundles which have cooling water circulating through them. This condenses the steam back to water, so rapidly that it creates a partial vacuum of 1.5–2.0 in Hg (5–7 kPa) in the condenser. The vacuum in effect creates a force which sucks the steam from the last stages of the turbines. From the bottom of the condenser, powerful pumps force the condensate back to the feedwater heaters to restart the cycle. The waste heat in the separate cooling water circuit must be removed to maintain its ability to cool as it circulates. This is done by pumping it through either natural draft or forced draft cooling towers, which reduce the temperature 20–30 °F (11–17 °C) by evaporation. The circulation flow rate of the cooling water in a 500 MWe unit is about 120,000 US gallons per minute (7.6 m3/s) at full load.

The condenser tubes are made of brass or stainless steel to resist corrosion from either side. Nevertheless they may become internally fouled during operation by bacteria or algae in the cooling water, or by mineral scaling, all of which inhibit heat transfer and reduce thermodynamic efficiency. Many systems include an automatic cleaning system which circulates sponge rubber balls through the tubes to scrub them clean without needing to take the system off-line.

Stack gas path & cleanup

As the combustion gas exits the boiler it is routed through a rotating flat basket of metal mesh which picks up heat and returns it to incoming fresh air as the basket rotates, This is called the air preheater. The gas exiting the boiler is laden with fly ash, which are tiny spherical ash particles, and contains the carbon dioxide, sulfur dioxide, and nitrogen oxide combustion gasses. The fly ash is removed by fabric bag filters or electrostatic precipitators. Once removed, the fly ash byproduct can sometimes be used in manufacture of concrete. Where required by law, the sulfur and nitrogen oxide pollutants are removed by stack gas scrubbers which use a pulverized limestone or other alkaline wet slurry to neutralize and wash the acid gases out of the exit stream. The gas travelling up the smoke stack may by this time only have a temperature of about 120 °F (50 °C). The smoke stack may be 500–600 ft (150–180 m) tall to dilute and disperse the remaining smoke components in the atmosphere.

Super critical steam plants

Above the critical point for water of 705 °F (374 °C) and 3212 lbf/in³ (22.1 MPa), there is no phase transitionfrom water to steam, but only a gradual decrease in density. Boiling does not occur and it is not possible to remove impurities via steam separation. In this case a new type of design is required for plants wishing to take advantage of increased thermodynamic efficiency available at the higher temperatures. These plants (also called once-through plants because boiler water does not circulate multiple times) require additional water purification steps to ensure that any impurities picked up during the cycle will be removed. This takes the form of high pressure ion exchange units called condensate polishers between the steam condenser and the feedwater heaters.

Nuclear power plants generally cannot reheat process steam due to safety requirements for isolation from the reactor core. This limits their thermodynamic efficiency to the order of 34–36%. Subcritical fossil fuel power plants can achieve 36–38% efficiency. Super critical designs have efficiencies in the low to mid 40% range, with new "ultra critical" designs using pressures of 30 MPa and dual stage reheat reaching about 48% efficiency.

Gas turbine combined cycle plants

An important class of fossil power plant uses a gas turbine, sometimes in conjunction with a steam boiler "bottoming" cycle. The efficiency of a combined cycle plant can approach 60% in large (500+ MWe) units. Such turbines are usually fuelled with natural gas or light fuel oil. While highly efficient and very quick to construct (a 1000 MW plant may be completed in as little as two years from start of construction), the economics of such plants is heavily influenced by the volatile cost of natural gas.

Simple-cycle gas turbine plants, without a steam cycle, are sometimes installed as emergency or peaking capacity; their thermal efficiency is much lower. The high running cost per hour is offset by the low capital cost and the intention to run such units only a few hundred hours per year.