



## HOW ELECTRICITY IS PRODUCED AT A COAL-FIRED POWER STATION

An overview of power generation at a modern coal-fired power station.

### INTRODUCTION

In South Africa, most of the electricity comes from thermal power stations, fuelled by coal. Most of these coal-fired stations consist of six generating units. Each production unit has a boiler, and turbine that drives a generator as well as control and auxiliary support systems.

The following describes how a 618MW boiler/turbine generating unit, such as those installed at Lethabo Power Station, produces electricity.

### CONVERTER OF ENERGY

**A power station is a converter of energy.** The combustion of fuel, a chemical energy conversion process, generates heat to convert water into steam at a very high temperature and pressure. The heat energy contained in the steam drives the turbine, converting heat energy into mechanical energy. Coupled to the turbine shaft is a generator. The kinetic energy of the spinning turbine does work in the generator that turns it into electrical energy.

### THE BOILER

#### Combustion

Lethabo Power Station burns 50 000 tons of coal every day, enough to fill 1 500 trucks carrying 33 tons each. Conveyor systems are used to transport the coal from a nearby mine to a coal stockyard and then to the power station site. The purpose of the coal stockyard is to ensure that there is sufficient coal reserves available to keep the power station in operation should the mine experience production problems.

Inside the power station, the coal is pulverised to a fine powder in giant grinding mills. This is because pulverised coal burns quickly, like gas. The pulverised coal is transported to the boiler furnace with air where it burns. Boilers, as high as a 35-storey office block, are the rectangular blocks that give power stations their distinctive look. They have been designed to use the energy released by the burning coal to heat water as efficiently as possible.

The mixture of pulverised coal and hot air is blown into the furnace through the front and rear walls of the boiler via 36 fuel injection ports, or burners. Here it ignites to create a fireball.

Two forced draught fans supply atmospheric air, pre-heated in air heaters to approximately 250°C, as combustion air to the boiler. The fire inside the boiler is initially started by injecting fuel oil at a high pressure into the furnace through nozzles. The oil is atomised and then ignited with a propane gas ignition system. The temperature inside the furnace is  $\pm 1200^{\circ}\text{C}$  at full load.

Not all the heat energy released through the combustion process is used to heat the water and steam in the boiler tubes. To efficiently use the heat energy produced, the exhaust flue gases are used to preheat the water and air entering the boiler.

Induced draught fans are used to extract the flue gases (exhaust gases) from the boiler. The flue gases are emitted into the atmosphere through two 275m tall smokestacks. This only happens after the particulate matter have been removed from the gas, by means of equipment such as electrostatic precipitators or bag filters (at some power stations), and gas conditioning systems – flue gas conditioning systems (FGC). The latter are only installed at the new built coal-fired power stations, Kusile and later at Medupi.

## **Steam production**

Lethabo boilers are of the natural circulation drum-type design. Very pure water, demineralised water, (to prevent corrosion) enters the boiler through an array of pipes, called the economiser, situated in the exhaust flue of the boiler. From the economiser, the water flows into the steam drum which acts as a steam/water reservoir and separator. Situated 73m above ground level, the drum is 24m in length, 2.21m in diameter and weighs a massive 259tons. The operational pressure inside the drum is 18.1MPa.

From the bottom of the drum, water flows via seven large bore pipes, called downcomers situated on the outside of the boiler, to distribution headers at  $\pm 10$ m above ground level. These downcomers are connected to tubes, the steam generation tubes (furnace wall tubes), which form the four walls of the boiler. These tubes eventually re-join the drum through a network of pipes that also forms the roof of the boiler. Inside the drum, which is at saturation temperature of  $\pm 350^{\circ}\text{C}$ , the steam is separated from the water. To use up yet more of the heat generated through the combustion process, steam from the top of the drum (saturated steam) flows to banks of tubes, superheaters, situated in the gas pass area of the boiler. Here the hot flue gas is used to further superheat the steam to a temperature from  $+350^{\circ}\text{C}$  to  $535^{\circ}\text{C}$ . There are three stages of superheating: primary, platen (2 banks) and final superheater. The primary stage is situated in the rear gas pass and the platen (of pendant design) in the front gas pass. The platen superheater is positioned very close to the top of the combustion area of the boiler which means that it is exposed to very high flame temperatures of  $\pm 900^{\circ}\text{C}$ . The final superheater stage is placed in the crossover (nose) between the front and rear gas passes. The superheated steam leaves the boiler and flows to the high pressure (HP) turbine at a temperature of  $535^{\circ}\text{C}$  and  $\pm 500\text{kg/s}$ . This is called live steam.

Lethabo boilers have a re-heat system. The exhaust steam (cold reheat) from the HP turbine, flows through primary and secondary reheaters, where steam is re-heated to  $535^{\circ}\text{C}$ . It then flows to the intermediate pressure (IP) and low pressure (LP) turbines to complete the cycle. The first stage reheaters are placed in the rear gas pass area with the second stage (final) reheater, in the crossover between the front and rear gas pass.

For boiler start-up operation and in the event of a large load rejection by the turbine, the HP turbine bypass system is provided to keep the boiler in operation. This system allows steam from the boiler final superheater outlet to pass, via a pressure reducing valve, to the cold reheat inlet. On return from the boiler, the reheated steam enters the condenser through an IP/LP bypass system to reduce the steam pressure. An attemperator is also used to reduce the steam temperature to the condenser temperature ( $\pm 40^{\circ}\text{C}$ ). This bypass system allows the boiler to be operated independently, i.e. without the turbine running. The boiler could remain in operation of  $\pm 30\%$  MCR.

## **THE TURBINE - IMPULSE TYPE**

Each of the six turbo sets has a high pressure (HP) turbine, an intermediate pressure (IP) turbine and two double-flow low pressure (LP) turbines, all arranged in tandem configuration. The turbine rotor operates at a rotational speed of 3 000rev/min that represents a frequency of 50Hertz on the Eskom national grid.

The HP and IP cylinders have an inner and outer casing. These reduce the impact of the high live steam pressure, primarily at the HP turbine, and also increase the thermal flexibility of all turbine casings (thinner wall thickness), allowing for fast start-ups and rapid load variations. Thinner casing walls can warm and cool easier so that there is less stress placed on the material.

Within the turbines, the thermal (heat) energy and pressure is changed into mechanical rotating energy. The HP and IP turbines comprise ten stages each, while the LP turbines consist of six stages per flow (4), totalling 26 stages. Each turbine rotor stage utilises a specific amount of heat energy required for rotational energy towards the total output of the generator rotor. In this way, the turbines extract most of the available thermal energy from the steam expansion. Towards the final stages they require about 16500 times more volume than at the HP inlet. Each of the turbine stages contributes to the total 618MW output of the generator. The HP turbine delivers 154,5MW (25%), the IP turbine 278,1MW (45%) and the two LP turbines 92,7MW (15% each) at design point.

The turbine and generator efficiency tests revealed that 635MW continuous operation is allowable at given steam conditions, while the maximum allowing capacity is 647MW.

The high pressure steam (16.1 MPa) at a temperature of 535°C, is piped through high pressure steam pipes to the HP turbine. The high pressure steam arrives from the boiler in pipes wrapped in thick insulation to prevent thermal energy losses. The steam enters the turbine (HP and IP) via emergency stop valves (ESVs) and control valves to regulate the steam flow into the turbine. These valves are hydraulically operated.

The turbine rotates by using two sets of blades. One set is fixed to the turbine's inner casing and directs the flow of steam. The other is fixed to the rotor and turns the rotor by taking energy from the fast moving steam. The design of these moving blades is critically important, and engineers have refined their shapes, similar to those in a jet engine, to extract the maximum energy from the steam.

The steam jets into the high pressure turbine first and travels through the various stages in a fraction of a second. The energy is absorbed, reducing pressure and temperature, while significantly increasing the volume. To make even more use of the steam produced, it returns to the boiler where it is reheated to 535°C in tubes placed in the boiler's gas pass. The steam enters the reheaters at a pressure of 4,2MPa and a temperature of 330°C.

The reheated steam returns to a slightly larger IP turbine at a temperature of 535°C and a pressure of 3.7MPa. The exhaust steam from the IP turbine, at 0,29MPa and 204°C, flows to the last part of the cycle where it expands through two large double flow LP turbines.

## **CONDENSATION**

As purified (demineralised) water is expensive, it is used again and again. In order to do this, the spent steam from the LP turbines, at a pressure of between 6 and 7kPa (absolute), and a temperature of ±40°C has to be condensed. Huge surface condensers are used in this process.

A condenser is basically a shell filled with 32 000 brass/titanium tubes. The spent steam from the turbine enters the shell and comes into contact with the cold outer surfaces of the tubes. Water from a cooling water system flows through the tubes. As a result of the difference in temperature between the spent steam (approximately 40°C) and the cold water (19°C) condensation is achieved.

Cooling water is supplied to the individual condensers by the cooling water supply pumps, at a rate of 11.03m<sup>3</sup>/sec.

The waste heat goes to the cooling towers. In these amazing "chimneys" warm water from the condensers is sprayed onto layers of plastic grid, spreading the water over a large surface area. A draught of cold air, moving upward through the falling water, reduces the temperature. The cooling air rising to the top of the tower, becomes warm and moist, and condenses when it reaches the colder air at the top. This means that the cloud or plume at the top of a cooling tower is not smoke, but condensing water vapour.

Although heat energy and water is lost inside the cooling towers, this is still the most efficient water cooling method.

At some of Eskom's power stations, direct and indirect dry-cooling systems are in use. Although quite expensive to build, they are designed to conserve water, and use approximately 60% less water than the conventional wet cooling system described above.

## **THE GENERATOR**

The turbines are linked directly to the generator rotor and rotate at 3 000 revolutions per minute. Inside the generator casing are thousands of copper wire coils fixed in a circle, called the stator. Inside the stator ring is a rotor.

As the rotor turns, its magnetic poles pass across a coil, producing a continuously varying current. The coils are arranged in three groups, in turn producing the current in three sets of windings. This is called 3-phase current and is a way of making the most of the rotation of the generator. The result is the alternating current (AC) produced by all power stations.

The generator produces a current of 13 500 amps, at 20 000 volts, which passes from the generator via conductors (bars) and a circuit breaker to the generator transformer. Here the voltage is stepped up to 275 000 volts and the current flow reduced to  $\pm 1\ 000$  amps.

From the transformer, the power is fed onto Eskom's integrated power grid. All power stations are synchronised to the grid at 50Hz.

## **CONTROL**

Each of Lethabo's six boiler-turbine sets (production units) is run as a separate entity with its own controls and instrumentation.

- There are three unit control rooms, each serving a pair of production units.
- The outside plant control room serves all auxiliary plant such as coal and ash conveyers, air compressors and auxiliary water systems.
- Water Treatment Plant is controlled from a separate control room.
- Operators in the Station Control Room are in permanent contact with Eskom's National Control Centre.

Operators monitor and control the computerised functions associated with start-up, normal operation, shutdown and emergency operation.

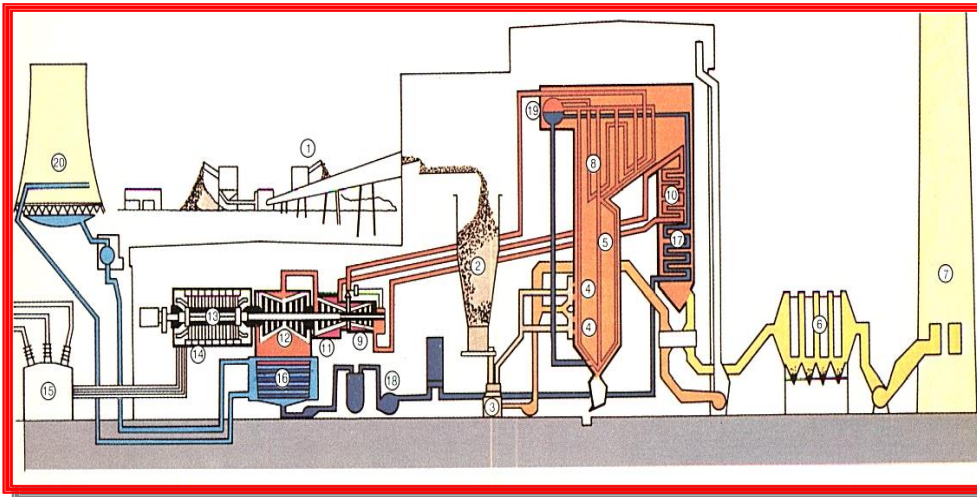
The control equipment for an entire unit consists of an integrated system of modulation and binary control, as well as alarm and supervisory functions. The control facilities ensure safe and efficient operation at all times requiring a minimum number of skilled operators.

All operations for normal, cold, warm or hot start-up, loading and deloading and normal shutdown of the unit are conducted from the control room, either manually, partially automatic or in fully automatic mode.

The modulating control system provides fully automatic load control of the whole process, with facilities for set point control of sub-loops as well as manual control of each drive. Similarly, the binary control provides fully automatic run-up of the major plant groups including the facility of individual drive control. In the event of the failure of running auxiliaries, standby plant is automatically switched on. If main plant groups fail, the unit automatically runs back to the highest possible safe state.

Data logging computers continuously monitor the main operating alarm systems, and provide a constant flow of information on video screens and printouts.

All the above operational functions are monitored on a 24-hour basis.



1. Mine
2. Coal Bunker
3. Coal Mill
4. Boiler Burners
5. Furnace
6. Bag Filters or Precipitators
7. Smoke Stack
8. Superheated Steam Tubes
9. High Pressure Turbines
10. Re-heating Steam Tubes
11. IP Turbines
12. LP Turbines
13. Generator Rotor
14. Stator
15. Transformer
16. Steam Condenser
17. Feedwater Heating
18. Feedwater Supply Pump
19. Steam drum
20. Cooling Tower

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 Select the "About electricity" and "Facts and Figures"