The Kusile power station is a six unit, 4,800 megawatt (MW) supercritical coal-fired power plant that uses a direct dry cooled condenser and pulse jet fabric filter plant with flue gas desulfurization technology to manage emissions.

It is 30 percent larger than the average coal-fired power plant in South Africa. When completed in 2020, it will be the largest power plant in Africa, the fourth-largest coal-fired power plant in the world, and the largest such plant in the Southern hemisphere.

Kusile power station is located in Mpumalanga province, around 100 km from Gauteng, the economic hub of South Africa with a population of 13.2 million people. The plant is owned by Eskom, which supplies around 90% of South Africa’s power. Kusile will act as a base load plant to address the severe power shortages that South Africa has experienced since 2007. The power will be fed into the national grid and contribute about 12% of South Africa’s generating capacity.
The coal-fired generating process
A coal-fired power plant generates electricity by burning pulverized coal to heat a water-filled boiler, basically a large kettle. The boiling water produces masses of steam, which is fed into a turbine converting steam energy into rotational energy that turns an electrical generator and transforms the rotational energy into electricity. Steam exiting the turbine is converted back into water by means of a cooling system (condenser), and the cycle begins again. Water is pumped back into the boiler with large feed water pumps, again converted into steam, to drive the turbines and generate more electricity.

What is a supercritical power plant?
The term supercritical refers to the pressure and temperature conditions of steam produced by the boiler. It is a critical point in the water vapor cycle, a thermodynamic state in which there is no clear distinction between water as liquid and water as gas. Water reaches this state at a critical pressure above 22.1 MPa and a temperature of 374°C. In simple terms, at this state no extra heat is needed to convert the water to steam (latent heat).

Most power plant boilers are subcritical. In these boilers, the water exists in two distinct phases, namely water and steam. At these pressures, extra heat must be added to convert water into steam (latent heat).

The supercritical thermodynamic cycle has efficiencies of 40-42 percent, compared to 36-37 percent in subcritical power plant cycles, which typically have boiler pressures of around 16 MPa and temperatures of 540°C. Higher thermodynamic cycle efficiency means:

- Lower fuel consumption
- Lower per-MW infrastructure investments
- Lower emissions
- Lower auxiliary power consumption
- Reduced water consumption

Greater boiler efficiency also improves operational flexibility by enhancing temperature control and load change flexibility, reducing start-up times and improving variable pressure operation. Supercritical plants do have much higher water quality requirements.

Kusile supercritical power plant
The core plant consists of six supercritical boiler turbine units operating with pulse jet fabric filter (PJ FF) and flue gas desulfurization (FGD) systems. To support the core process of power generation, a number of other systems are needed which are known as the balance of plant (BoP); these include:

- Material handling plant for coal and ash management, as well as transport to and from the power island
- Water treatment plant and condensate polishing plant (CPP) to provide high-quality water for the steam generation plant, as well as potable and raw water for various auxiliary power plant demands
- Wastewater treatment plant to ensure optimum management of plant wastewater
- Fuel oil and gas plant to support the boiler combustion process
- Electrical reticulation system, including all boards, transformers and backup diesel generators
- FGD and PJ FF systems for environmental control
- Air cooled condenser (ACC) for steam condensation
- Low-pressure service for processes such as auxiliary cooling and the compressed air plant
- Common FGD, including limestone handling
Flue gas desulfurization (FGD) process, controlled by an ABB DCS

Schematic diagram of thermal power generation

**ABB’s responsibilities and scope of supply**

ABB is responsible for the control and instrumentation of the entire plant, including all six units and the balance of plant – all of which will be seamlessly integrated and operated from a single control platform.

ABB is responsible for the design, manufacture, commissioning and testing of the DCS, the field equipment and the associated cabling infrastructure for the entire Kusile plant. To realize this enormous automation project ABB has drawn on its strong local engineering resources in South Africa and combined this with its global
engineering expertise sourced primarily from Italy and Germany. This core team has been supplemented with skills drawn from ABB’s European and Indian operational centers to create a truly international project team for Kusile.

To automate a plant of this size and complexity requires over 200,000 I/O signals – far more than the 115,000 I/Os that a typical subcritical power plant requires (see relevant table)

When the Kusile power plant is completed, ABB will have supplied:

- 1 power island control room and 3 ancillary control rooms
- 207,000 hardwired I/Os
- 87,000 software I/Os
- 755 cubicles
- 160 servers
- 156 monitors
- 700 km of cables
- 100 km of fibre-optic cables
- 4,000 junction boxes
- 14,900 instruments
- 11,800 temperature transmitters
- 3,100 pressure transmitters
- 48 km impulse piping
- 9,000 welds

**Kusile has several automation firsts**

Eskom had several specific requirements for this project, some of which are automation firsts in South Africa.

**A single control and protection system for the entire plant**

For the Kusile project, Eskom required a unified platform for all control systems across the plant to:

- Minimize warehousing of spare parts
- Maximize equipment interchangeability
- Simplify life-cycle management of C&I technology used in the plant
- Reduce training requirements for operators, engineers and maintenance personnel
- Reduce overall staff requirements by using one technology platform

ABB more than met these requirements, delivering not only a single DCS platform, but also providing a protection solution on the same Melody Rack hardware platform. This is the first time that any automation vendor has done this in South Africa.

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**To automate a plant of this size and complexity requires a huge number of input/output (I/O) signals:**

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<table>
<thead>
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<tbody>
<tr>
<td>Number of hardwired signals per generating unit (x6)</td>
<td>24,000</td>
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<tr>
<td>Number of hardwired signals BoP</td>
<td>49,000</td>
</tr>
<tr>
<td>Number of soft signals</td>
<td>14,000</td>
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<tr>
<td><strong>Total I/Os for Kusile supercritical power plant</strong></td>
<td><strong>207,000</strong></td>
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**A single operator technology for the entire power plant (unit, electrical and common systems):**

- Simplifies life-cycle management of operator technology used in the plant, because maintenance and migration strategies are common throughout the entire station
- Operators need only be familiar with one human machine interface (HMI), which greatly simplifies training and support
Kusile is the first plant with FGD (wet process) in South Africa and Africa as a whole.

Kusile has to comply with the new plant SO₂ minimum emissions standards under the South African National Environmental Management Air Quality Act (NEM: AQA), which stipulates that for coal-fired power stations, daily average SO₂ emissions should not exceed 500 mg/Nm³.

Kusile is the first plant ABB has designed with a centrally managed system covering the entire generating unit and the BoP DCS for:

- System backup and restore
- Virus signature deployment

Again, this was an Eskom requirement for the C&I installation project at Kusile, and ABB engineered a solution to meet all of Eskom’s requirements.

The benefits of a centrally managed system include:

- One universal solution for backup and virus deployment for the entire ABB system, simplifying system maintenance and minimizing training requirements
- Minimal staffing requirements with only one central system to look after (one virus deployment and one backup system)
- Ensures all anti-virus signature file deployment is universal and consistently applied
- ABB backup and antivirus system is fully automated, minimizing human error and staffing requirements

ABB is seamlessly integrating the GE (Alstom) turbine control and protection system into the ABB operator interface and automation system to ensure a uniform view of the process (faceplates, alarms and information).

This ensures Eskom operators have only one operator interface to train on, and provides all of the advantages listed above under ‘single operator technology.’

The plant has three safety systems, which are implemented on a Melody SIL3-rated platform. The plant requires two ABB SIL3-rated protection systems for the water, steam and boiler protection systems. A further protection system is required for the BoP fuel oil system. For the whole plant, ABB is therefore providing a total of 13 SIL3-rated safety systems. This is the largest solution of its kind in the world.

Unit control concept - MODAKOND

The South African electrical grid has some unique attributes that make it essential for coal-fired power plants to be extremely flexible in their operating ranges, as well as in their ability to support the grid during incidents resulting from the loss of generating units. This is because:

- Most of the generation deployed in South Africa includes large coal-fired units (the average size of which is about 600 MW)
- Minimal numbers of gas turbines to support peaking demand
- Zero or very limited ability to import power from surrounding countries, which have very small grids amounting to less than 3 percent of South Africa’s 37,000 MW generating capacity
- South Africa’s large transmission network, with power plants mostly located in one central area

The Eskom specification called for ABB to implement the Alstom/GE concept for unit coordinator control of the power plant. After discussions, both Eskom and Alstom accepted ABB’s proposal to use ABB’s patented solution for unit coordinator control, MODAKOND.

As a model-based unit control for coordinating the boiler and turbine, MODAKOND provides significant advantages for Eskom, including:

- Faster load ramps for increased flexibility
- Reduced minimum load for low-load operation
- Capacity to provide grid services, in particular primary and secondary control, making the unit attractive for the load dispatcher and increasing profitability
- Improved plant efficiency for primary frequency control through reduced throttling of turbine control valves
- Precise control of variable manipulation results in smoother operation of main components such as pulverizers, FD- and ID-fans, reducing plant operational costs and downtime
Project documentation requirements
The basis for completing any engineering activity is the project documentation requirements. These were clearly defined for each and every major activity, from engineering, installation and commissioning to the maintenance and training stages of the project.

All documentation produced on the project must comply with IEC 61355, VGB B103, VGB R170 C and VGB R 171 standards. Project documentation demands were by far the largest and most comprehensive ever required on a project of this scope. At the peak of the engineering work, ABB had a team of around 100 engineers preparing designs and documentation.

For each unit, the design documentation for the major milestone design freeze (i.e., after Eskom has authorized procurement, manufacture and detailed design to commence) that ABB has to issue consists of more than 1,000 individual documents needing customer approval. For the entire project phase of each unit, the engineering team is required to issue around 4,000 documents for various activities.

Bus technologies
ABB has applied a number of bus technologies to interface to the various third-party systems, such as Profibus, IEC 61850, IEC 101/4, Modbus, OPC, Ethernet over radio.

Training
In response to Eskom’s project training requirements, ABB has developed 14 Kusile-specific training courses that will be held in 46 sessions with an average participation of eight people per session. By the end of the project, ABB will have trained around 368 people.

Training includes three unit operator high-fidelity simulators in service prior to the start-up of the first unit for upfront operator training.

The unique technical activities for the Kusile project have added to ABB’s technical expertise and will be transferable to other projects.

RAM and FMECA requirements
RAM (reliability, availability, maintainability)
As part of the technical requirements for the project, ABB had to meet very high values for system availability: 99.99 percent for the DCS portion (equal to downtime of less than 53 minutes per year) and 99.99 percent for the protection systems (equal to downtime of less than six minutes per year).

To achieve this, ABB had to take great care during the design phase to ensure that the systems distribute the redundant mechanical functions across the DCS. The design, together with the inherent redundancy and reliability of the DCS platform, enabled ABB to confirm to Eskom via a mathematical reliability study that the system is able to meet the required reliability figures.

FMECA
(failure mode, effects and criticality analysis)
As part of the engineering deliverables, ABB was required to perform a complete FMECA study on its design. This required analysis of every single input and output of the DCS system and a look at all the possible failures and their impact on plant systems and specific equipment. This was a mammoth task, as it potentially involved analyzing nearly 75,000 individual signals for unit 1, as well as the BoP scope. In order to streamline this process, ABB proposed a way to reduce the need to analyze all of the I/O based on the way we had distributed the functions and plant in the DCS design. This in turn allowed us to minimize the overall engineering effort required to produce the FMECA study. The results of the FMECA study did identify certain shortcomings in our allocation of I/O, and we made the necessary corrections prior to commissioning.

The lessons learned from the results of performing the RAM and FMECA studies will be carried forward to future ABB projects, and enable ABB to provide reliable and safe DCS designs for future customers.

Alarm management
For this project ABB had to manage implementation of all the process alarms provided by various mechanical plant suppliers during the design phase, prior to commissioning.

The work involved identifying all alarms in the system, and then meeting with various process suppliers to review and confirm all the alarms, as well as the expected operator response to them. Eskom documented and signed off on all of this information.
Approximately 50 alarms can be reviewed, discussed and documented per day, and there are 11,000 unique alarms for one unit and the BoP.

ABB has also developed a special add-in to the operator interface aspect system (right mouse-click) for the Kusile project, which enables the operator to easily access documented alarm responses to fulfil the required functionality. On receiving any alarm, an operator can immediately access a detailed description of actions that should be taken to address the problem.

**Advanced diagnostics**
Advanced diagnostics supports the maintenance personnel in checking up the equipment and provides an accurate failure analysis. The application blends in a powerful and intuitive environment the information acquired from vibration analysis, process data, performance calculation and reference data (baseline), provided by a state-of-the-art machine-learning algorithm. The plant maintenance efficiency is therefore greatly enhanced by reducing the relevant cost and providing an effective predictive maintenance.

This greatly increases operator efficiency, because plant disturbances and alarms can be handled immediately and actions taken quickly, increasing overall plant availability.

**Cyber security**
As part of the project contract, ABB had to provide comprehensive cyber security solutions to comply with requirements in VGB-R 175 on IT security for power plants. The boundaries of Kusile’s C&I system had to be protected from intrusions via demilitarized zones using redundantly configured unified threat managers (UTM).

**Other ABB solutions for the Kusile power station**
ABB is also supplying a wide range of electrical solutions for the Kusile power station. These include:

**MV switchgear (6.6 kV & 15 kV)**
- BoP has 46 MV boards; each unit has 9 MW boards; total: 100
- Largest ever switchgear order for South Africa, and the largest order assembled in ABB's South African factory
- Panels: 100 per unit = 600; 328 for BoP; total 928
- Supply, manufacture, FAT, delivery, supervision of erection, commissioning and documentation
- Key products include the ABB Unigear ZS1 indoor air insulated switchgear for primary distribution, the latest ABB Relion range of control products, and the REA (fastarc protection system) range of protection relays. Installing 1xREA101 per board, 100 for the entire plant

**Substation automation system (MicroSCADA and IEC 61850 network)**
MV boards
- BoP: 288 IEDs; 107 IEDs per unit; total: 930
- IEDs used: REM 630, REF 630, RET 630 and RED615 and RED670
- Supply, engineering and commissioning

LV boards
- Supply to Siemens, engineering and commissioning
- BoP 62; per unit: 23; total 200
- All IEDs are on IEC 61850 NW and connected to a MicroSCADA workstation in the electrical control room. Full functionality: Operate (everything except motor/actuator feeders), monitor and engineer. Not used for operating at the moment. Central redundant server for entire system located in BoP equipment rooms; gateway in each unit
- System also contains ABB AGFS network switches
- BoP 42; per unit: 14; total 126

ABB RTU540 for raw water supply control Provides control and monitoring for the supply of raw water to Kusile power station. Water is supplied from Eskom's Kendal power station raw water reservoir.
- 8 x ABB RTUs; 2 x RTU560, 6 x RTU540
- 8 radios ABB ARP400 (Racom) connect the locations to each other