Eskom is at the forefront of power generation technology. Vast and imaginative schemes have assured Eskom’s prominence in the energy world and attracted international attention from related sectors. Technical information is the key to a professional understanding of this multi-disciplinary engineering project.

Revised October 2005

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A BARRIER OVERCOME

Introduction

On one side of the watershed the Tugela River carries its waters almost unused to the Indian Ocean. On the other, the Vaal River flows towards the Atlantic, its potential exploited to the utmost. In the early 1970s demands made on the Vaal were growing relentlessly and problems of future water supply for industry, commerce and domestic use in the Gauteng area were becoming increasingly serious. The solution was obvious – transfer water from the catchment area of the Tugela to that of the Vaal.

As water transfer over the Drakensberg would require the construction of reservoirs, channels and pumps, it opened the way to build a hydroelectric power station which could further exploit the potential of water resources being made available. The Department of Water Affairs and Forestry (DWAF) and Eskom started work on this dual-purpose scheme in 1974. In 1982 the project was completed, operating as a pumped storage scheme and as a pumping station for water transfer over the Drakensberg from the Tugela to the Vaal.

Almost the whole complex was constructed underground and the surface buildings and access roads were built in such a way that they can hardly be seen as a result the beautiful natural surroundings appear virtually untouched.
Pumped storage schemes

The pumped storage scheme is a variation of the more common run-of-river hydroelectric power stations. The power station of the pumped storage scheme is built on a waterway that links an upper and lower reservoir. Electricity is generated only during peak demand periods or emergencies by channeling water from the upper to the lower reservoir through reversible pump-turbine sets. During periods of low energy demand this same water is pumped back from the lower to the upper storage reservoir by the reversible sets.

The Drakensberg scheme paved the way for Eskom’s second pumped storage project at Palmiet in the Cape. These power stations have the advantage of being able to generate electricity within three minutes, whereas coal-fired stations require a minimum of 8 hours from cold startup to start generating power.

By pumping water from the lower to the upper reservoirs during low-peak periods, both the Palmiet and Drakensberg schemes help to flatten the load demand curve of the national system by using the excess generating capacity available in these off-peak periods.

Tugela-Vaal water transfer scheme

South Africa’s major industrial and mining activities are centred in the Gauteng area, which is dependent on the Vaal River for its water supplies. The Vaal’s capacity of 1.545 billion m³ a year was sufficient to meet demands until 1974. By transferring water from the Tugela River over the Drakensberg escarpment and into the Wilge River, a tributary of the Vaal, the DWAF calculated it could increase the Vaal’s capacity to meet demands until 1992.

Studies showed that the best advantage would be derived from storing the water in a deep reservoir with limited surface area to minimise evaporative losses. This would permit the level of the extensive and wasteful Vaal Dam to be reduced to previously unacceptable levels. In times of need, water from the reservoir could then be released into the Vaal Dam.

The scheme provides for the annual transfer of 631 million m³ of water and an annual storage capacity of 2.660 million m³, which increases the Vaal’s yield to 2.345 million m³ – 52% more than the natural yield.

The Driel Barrage is situated just below the confluence of the Mlambonja and the Tugela Rivers.

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### Operating data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation energy equivalent</td>
<td>27.6 GWh</td>
</tr>
<tr>
<td>Surface area when full</td>
<td>6 937.0 ha</td>
</tr>
<tr>
<td>Catchment area</td>
<td>191 km²</td>
</tr>
<tr>
<td>Maximum discharge of spillway</td>
<td>2 x 500 m³</td>
</tr>
<tr>
<td>Capacity of outlet works</td>
<td>220 m³</td>
</tr>
<tr>
<td>Type of operational cycle</td>
<td>Weekly</td>
</tr>
<tr>
<td>Cycle efficiency</td>
<td>73.7%</td>
</tr>
</tbody>
</table>

### Electrical aspects

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>420 kV</td>
</tr>
<tr>
<td>Main civil work</td>
<td>Banghoep, Cogefar &amp; African Banghoep</td>
</tr>
<tr>
<td>Supply of aggregates</td>
<td>Hyposa Quaynes Ltd</td>
</tr>
<tr>
<td>Headrace civil work</td>
<td>Spa Banghoep</td>
</tr>
<tr>
<td>Surface building</td>
<td>SM Goldstein</td>
</tr>
<tr>
<td>Structural steelwork</td>
<td>Ganger Steel</td>
</tr>
<tr>
<td>Concrete</td>
<td>Kilscreen and Driekloof Dams Department of Water Affairs</td>
</tr>
<tr>
<td>Mechanical engineering</td>
<td>Ganger Steel</td>
</tr>
<tr>
<td>Pump-turbines, governors and</td>
<td>Messi representing Toshiba,</td>
</tr>
<tr>
<td>Pumped transformers</td>
<td>Voest-Alpine and Hitachi</td>
</tr>
<tr>
<td>Pump stations</td>
<td></td>
</tr>
<tr>
<td>Spillways</td>
<td></td>
</tr>
<tr>
<td>Type of spillway</td>
<td>1 controlled tunnel</td>
</tr>
<tr>
<td>Control room equipment</td>
<td></td>
</tr>
<tr>
<td>Power station cranes</td>
<td>Knap 5A (Pty) Ltd</td>
</tr>
<tr>
<td>Pipework</td>
<td>Mother &amp; Platt</td>
</tr>
</tbody>
</table>

### Construction / commissioning history

- **Commissioning**
  - First set: May 1981
  - Final set: May 1992

### Major dams in the Tugela-Vaal Scheme:

- **Woodstock Dam**
  - Full supply level: 1.176.64 md
  - Height above lowest foundation: 51.0 m
  - Length of crest: 760.0 m
  - Volume content of dam wall: 2.0 million m³
  - Gross capacity of reservoir: 381.0 million m³
  - Maximum discharge of spillway: 2 x 500 m³
  - Type of spillway: 1 controlled tunnel
  - Uncontrolled chute

- **Sterkfontein Dam**
  - Full supply level: 1.702 md
  - Height above lowest foundation: 93.0 m
  - Length of crest: 560 m
  - Volume content of dam wall: 17.0 million m³

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THE 6 m HEADRACE INLETS, SITUATED IN THE DRIEKLOOF DAM, HOUSE THE EMERGENCY / MAINTENANCE GATES
The construction of the halls was undertaken in stages, working downward from the central crown and inserting rockbolts according to a carefully designed pattern. The cavern walls were deteriorating. When rock movement became minimal, a second lining of shotcrete was applied with weldmesh reinforcement. The same techniques were applied to tunnelling.

**Headrace surge shafts:**

<table>
<thead>
<tr>
<th>Number</th>
<th>Internal diameter</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>14 m</td>
<td>89 m</td>
</tr>
</tbody>
</table>

**Active storage capacity:** 27.5 million m³

**Type of construction:** Cylindrical

**Pressure shafts and tunnels (penstocks):**

<table>
<thead>
<tr>
<th>Volume of concrete</th>
<th>Type of construction</th>
<th>Capacity of spillway</th>
<th>Type of spillway</th>
</tr>
</thead>
<tbody>
<tr>
<td>843 000 m³</td>
<td>Concrete-lined</td>
<td>220 m³</td>
<td>Baffled apron on embankment</td>
</tr>
</tbody>
</table>

**Gross capacity of reservoir:** 35.6 million m³

**Minimum level:** 1 680 masl

**Maximum flow velocities:** 6.4 m/s for concrete-lined sections, and 8.4 m/s increasing to 19.0 m/s at machines

**Non-overflow crest:**

- 1 702.44 m for steel-lined sections

**Maximum operating water level:** 1 702.0 m

**Number of machines:** 4

**Type of power station:** Underground power station

**Minimum operating water level:** 1 235.0 m

**Number of machines:** 4

**Kilburn Dam:**

- **Full supply level:** 1 256.0 masl
- **Minimum level:** 1 235.0 masl
- **Active storage capacity:** 27 million m³
- **Minimum storage volume:** 6.6 million m³
- **Height above lowest foundation:** 51.0 m
- **Length of crest:** 825.0 m
- **Volume of concrete:** 2.9 million m³
- **Gross capacity of reservoir:** 36.0 million m³
- **Capacity of spillway:** 320 m³
- **Type of spillway:** Side channel with chute
- **Non-overflow crest:** 1 235.0 m

**Spillway crest:**

- **Maximum operating water level:** 1 702.0 m
- **Number of machines:** 4

**Type of construction:** Cylindrical

Water is pumped at an average continuous rate of 20 m³/s from the Driel Barrage into a canal which leads to the Jagersrust forebay. From here it is pumped into the Kilburn reservoir, which is the lower reservoir in the Drakensberg Pumped Storage Scheme. The upper reservoir, Driekloof Dam, is situated in a branch of the Sterkfontein reservoir into which it overflows when full. The DWAF raised the wall of the Sterkfontein Dam to 93 m to increase its capacity to the desired 2 660 million m³.

When the DWAF received its first water from the Lesotho Highlands Project in February 1998, it was decided to shut down the Tugela-Vaal (TUYA) canal for a period of 2 years, commencing in June 1998, to upgrade the canal. The following works were undertaken:

- Relining of the canal with concrete, using the old lining as a base.
- Installation of an improved drainage system.
- Provision for the expansion of concrete slabs to prevent cracking, which was a major problem.

This also gave DWAF the opportunity to upgrade the installations of the electrical switchgear and pump instrumentation and to overhaul pumps and valves.

The reservoirs

Four major storage reservoirs were constructed within the Tugela-Vaal water transfer scheme: Woodstock, Kilburn, Driekloof and Sterkfontein.

**Woodstock:**

The Woodstock Dam regulates the flow of the Tugela River upstream of its confluence with the Mlambonja River before it enters Driel Barrage. The foundations of the embankment are built of sandstone, siltstone and mudstone. The zoned embankment itself is constructed from silt and sand alluvial deposits and weathered materials from the basin of the reservoir. The upstream slope is protected by dumped rip-rap, whereas the downstream slope has been grassed to combat erosion. A tunnel with a capacity of 418 m³/s carries normal discharge into a stilling basin, while a spillway chute caters for flood discharges estimated at 8 000 m³/s. The chute includes a curved ogee spillway section, a transition zone with the floor elevated along the centre line and an 11 m wide chute. A flip-bucket energy disperser at the end of the chute diverts the direction of the outflow towards the direction of the river flow. An auxiliary spillway is designed to cater for maximum floods of up to 2 730 m³/s.

**Kilburn:**

Kilburn Dam, in the foothills of the escarpment, is the lower reservoir of the Pumped Storage Scheme. Since the water level fluctuates over a depth of 21 m as the scheme operates, the upstream face of the dam has a flatter slope to improve its stability and is protected by rip-rap (dolerite). The downstream face is grassed. This not only combats erosion but blends in with the surrounding countryside.
Unlike normal hydroelectric generators, the generator motors run in both directions in a regular cycle. The severe fatigue stresses influenced the design of the stator core and windings.

The grid voltage of 400 kV. For several reasons, including security, the transformer is fitted with two oil/water and two water/water heat exchangers, one being a standby.

The high-voltage switchgear is gas-insulated with double busbars and phase-reversal isolators for changeover between pumping and generation. Installation is designed to allow ease of maintenance.

SF₆ technology was used for the switchgear so that it could be made compact enough to fit in the transformer cavern. The vertical circuit breakers each have three arc quenching units that are kept below the rated lightning-impulse withstand voltage of 1,425 kV for the switchgear and transformers.

Operational efficiency

Losses during pumping and generation mean that the scheme requires about 1.36 units of pumping energy for each unit generated. As the same plant is used for pumping and generation, the maximum theoretical load factor for generation is roughly 72%. The secondary role of the Drakensberg Pumped Storage Scheme (pumping water into the Sterkfontein reservoir for the DWAF) and the shape of the demand curve result in a maximum weekly load factor of about 42%.

Each machine at the Drakensberg scheme can be brought from standstill to full load within three minutes. The loading on each machine can be brought from speed-no-load to full load in approximately 80 seconds. The change from maximum pumping load to full generation can be effected in approximately eight minutes. This results in a load swing of 2,000 MW on the national grid.

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Cavitation posed a challenge since cavitation erosion increases exponentially with relative flow velocity. In the case of the Drakensberg machines, this velocity reaches nearly 20 m/s. Submergence of 65 m to 86 m below the level of the Kilburn reservoir guarantees that no unacceptable cavitation damage occurs, even when pumping against a maximum head. An interesting aspect of the machines is that they are controlled by electronic governors of the electrohydraulic type with proportional-integral-derivative characteristics. The control output is at the frequency of the generated power.

Each machine can be isolated from the water in the penstocks by its own spherical shut-off valve. These valves are 2.25 m in diameter and are operated by hydraulic servomotors. They can be closed during operational conditions, even when water hammer is taking place. A special upstream seal is provided for maintenance purposes.

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Electrical aspects

The generator-motor of the pump-turbines can run unloaded as synchronous condensers in the direction of generation rotation to provide reactive compensation. In this case, the spherical valves are shut and compressed air is used to depress the water in the draft tubes to below the level of the runner, thus minimising the torque. The excitation is then adjusted to give the required reactive compensation. The synchronous condenser mode of operation can be considered as a spinning reserve as it allows the machine to be loaded as a generator by releasing the compressed air from the turbine chamber and opening the spherical valve and guide vanes.

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