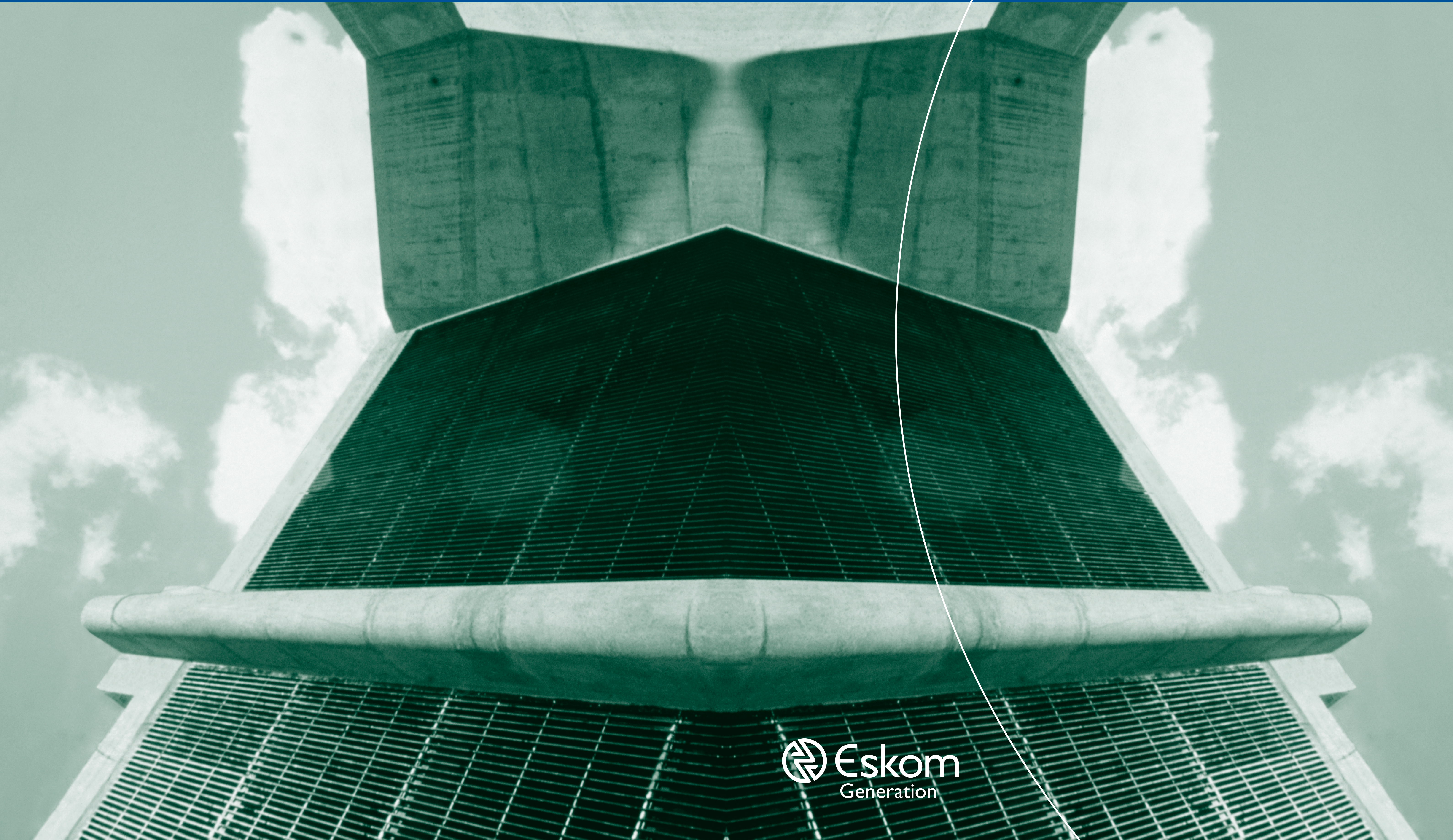
Eskom Generation

Eskom Holdings Limited Reg No 2002/015527/06

Drakensberg
PUMPED STORAGE SCHEME



Eskom Generation

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Eskom
Generation

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

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 channelling 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.

THE 6 m HEADRACE INLETS, SITUATED IN THE DRIEKLOOF DAM, HOUSE THE EMERGENCY / MAINTENANCE GATES

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 million m^3 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 m^3 of water and an annual storage capacity of 2 660 million m^3, which increases the Vaal's yield to 2 345 million m^3 – 52% more than the natural yield.

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

Operating data	
Generation energy equivalent to 27,0 million m^3	27,6 GWh
Time required to pump 27,0 million m^3 of water from lower to upper reservoir	39 hours
Type of operational cycle	Weekly
Cycle efficiency	73,7%
Electrical aspects	
Rated voltage	420 kV
Rated frequency	50 Hz
Lightning surge voltage	1 425 kV
Switching surge voltage	1 050 kV
AC voltage 50 Hz/min	630 kV
Rated current	2 500 A
Short-circuit current:	
Symmetrical	31,5 kA
Asymmetrical	38,6 kA
Single phase to earth fault	36,2 kA
Making current, peak value	92,4 kA
Construction / commissioning history	
Construction commenced	December 1974
Commissioning	
First set	May 1981
Final set	May 1982
Major dams in the Tugela-Vaal Scheme:	
Woodstock Dam	
Full supply level	1 175,56 masl
Type of dam	Earth fill
Height above lowest foundation	51,0 m
Length of crest	760,0 m
Volume content of dam wall	2,0 million m^3
Gross capacity of reservoir	381,0 million m^3
Maximum discharge of spillway	2 x 500 m^3/s
Type of spillway	1 controlled tunnel 1 uncontrolled chute
Sterkfontein Dam	
Full supply level	1 702 masl
Type of dam	Earth fill
Height above lowest foundation	93,0 m
Length of crest	3 060 m
Volume content of dam wall	17,0 million m^3

Gross capacity of reservoir	2 656,0 million m^3
Surface area when full	6 937,0 ha
Catchment area	191 km^2
Maximum discharge of spillway	2 x 500 m^3/s
Spillway	None
Capacity of outlet works	220 m^3/s
Major Contractors	
Civil engineering	
Exploratory excavation	Roberts Union Corporation
Preliminary civil work	Batignolle, Cogefar & African Batignolle
Main civil work	Drakon (LTA & Shaft Sinkers)
Supply of aggregate	Hippo Quarries Ltd
Headrace civil work	Spie Batignolle
Surface building	SM Goldstein
Structural steelwork	Genrec Steel
Kilburn and Driekloof Dams	Department of Water Affairs
Civil engineering consultants	Gibb, Hawkins & Partners
Mechanical engineering	
Pump-turbines, governors and spherical valves	Mitsui representing Toshiba, Voest- Alpine and Hitachi
Penstocks	Sorefame, Broderick
Gates and screens	Neyrpic-BVS Technics
Power station cranes	Krupp SA (Pty) Ltd
Pipework	Mather & Platt
Electrical-engineering	
Generator-motors	Brown Boveri
Cabling	Industrial Electrical Co
Transformers	ASEA Electric Co Ltd
SF6 metal-clad switchgear	Brown Boveri
Control room equipment	Siemens

TECHNICAL DATA

The reservoirs	
Upper reservoir: Driekloof	
Full supply level	1 700 masl
Minimum level	1 680 masl
Active storage capacity	27,5 million m^3
Minimum storage volume	8,15 million m^3
Type of dam	Rock fill
Height above lowest foundation	46,6 m
Length of crest	500 m
Volume content of dam wall	843 000 m^3
Gross capacity of reservoir	35,6 million m^3
Capacity of spillway into	220 m^3/s
Sterkfontein reservoir	
Type of spillway	Baffled apron on embankment
Non-overflow crest	1 702,44 masl
Spillway crest	1 700,0 masl
Maximum operating water level	1 702,0 masl
Minimum operating water level:	
Normal	1 684,8 masl
Emergency	1 680,0 masl
Lower reservoir: Kilburn	
Full supply level	1 256,0 masl
Minimum level for	
4 machines operating	1 235,0 masl
Active storage capacity	27 million m^3
Minimum storage volume	6,6 million m^3
Type of dam	Earth fill
Height above lowest foundation	51,0 m
Length of crest	825,0 m
Volume content of dam wall	2,9 million m^3
Gross capacity of reservoir	36,0 million m^3
Capacity of spillway	320 m^3/s
Type of spillway	Side channel with chute
Non-overflow crest	1 259,0 masl
Spillway crest	1 256,0 masl
Lowest operational level for	1 235,0 masl
4 machines generating	
Headrace tunnels:	
Number	2
Internal equivalent diameter	6,0 m
Length	1 502,1 m & 1 497,1 m
Type of construction	Concrete-lined
Maximum flow velocity	5,4 m/s

Headrace surge shafts:	
Number	2
Internal diameter	14 m
Height	89 m
Type of construction	Cylindrical
Pressure shafts and tunnels (penstocks)	
Number	2, each bifurcating to 2 machines
Length (up to spiral inlet)	1 614,3 m & 1 611,3 m
Type of construction	Concrete-lined except last 522,6 m
	& 494,3 m which are steel-lined
	in each case
Maximum flow velocities	6,4 m/s for concrete-lined sections, and
	8,4 m/s increasing to 19 m/s at machines
	for steel-lined sections
Underground power station:	
Number of machines	4
Continuous rating of each	250 MW at 0,9 power factor
machine for generation	
Maximum power for pumping	270 MW
per machine	
Range of net head for generation	400,0 m to 448,5 m
using 4 machines	
Range of pumping head	436,4 m to 476,0 m
using 4 machines	
Maximum permissible pressure	7,22 MPa
in the penstocks	
Type of pump-turbine	Single-stage, reversible Francis
Rated speed for both directions	375 r/min
of rotation	
Method of pump starting	Pony motor rated at 16,5 MW
Type of operation	Automatic
Type of control	Local and remote
Tailrace surge chambers:	
Number	2
Internal diameter	16,0 m
Height	81,6
Type of construction	Cylindrical
Tailrace tunnel:	
Number	1
Internal equivalent diameter	8,5 m
Length	1 402 m
Type of construction	Concrete-lined
Maximum flow velocity	5,4 m/s

Water is pumped at an average continuous rate of 20 m^3/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 m^3.

When the DWAF received its first water from the Lesotho Highlands Project in February 1998, it was decided to shut down the Tugela-Vaal (TUVA) 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.

Construction of the power station caverns

Environmental considerations as well as engineering requirements led to the decision to build the power station underground. Certain aspects of environmental conservation introduced during the construction of the Drakensberg Pumped Storage Scheme had a profound influence on Eskom's approach to the later Palmiet project. The scheme at Drakensberg witnessed the beginning of the integration of both environmental and technical principles, which was to be a hallmark of the Palmiet undertaking. Contractors and Eskom's engineers came to recognise the importance of the environmental protection and restoration and co-operated willingly in Eskom's endeavours to safeguard the natural surroundings. The rock in which the power station was built consists of relatively weak mudstone, siltstone and sandstone, which are horizontally bedded. Both primary and secondary rock reinforcement was used with fast-resin anchorages of 6 m and 3 m in length, respectively.

To reduce the maximum cavern span for the power station complex, separate halls were constructed for the valves, the pump-turbines and the transformers.

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 lined with shotcrete soon after excavation to prevent rock deterioration. When rock movement became minimal, a second lining of shotcrete was applied with weldmesh reinforcement. The same techniques were applied to tunnelling. During construction of the underground power station complex, 1 330 000 t or 510 000 m^3 of rock were excavated, and 220 000 m^3 of concrete and 45 000 m^3 of pneumatically applied concrete were placed. Some 6 000 t of reinforcing steel were used in the concrete, and the 75 000 rock bolts inserted amounted to 260 km of steel rods.

The reservoirs

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

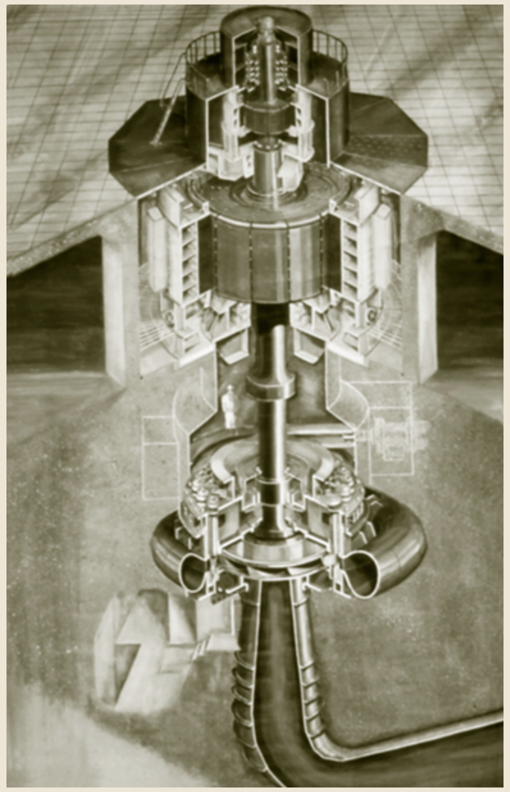
Woodstock

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 m^3/s carries normal discharge into a stilling basin, while a spillway chute caters for flood discharges estimated at 1 000 m^3/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 m^3/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 flattish 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.



CROSS SECTION OF A UNIT

The maximum emergency discharge from the power station in the direction of rotation is 312 m³/s, which is more than the estimated maximum flood discharge from the catchment area. The side-chute spillway is designed to cope with the flow rate during emergency generation. It has an energy-dispersing device downstream in the form of a hydraulic-jump stilling basin that includes baffle blocks. The embankment includes a baffled inlet chute for the continuous transfer of water at 11 m³/s from the Jagersrust forebay. The inlet was modified to increase this figure to approximately 20 m³/s.

Driekloof

Driekloof Dam, located in a branch of the Sterkfontein reservoir, is the upper reservoir of the Pumped Storage Scheme. It is partly submerged when Sterkfontein is full. During the weekly cycle of the scheme, the water level fluctuates over 22 m. The rockfill construction includes mud-stone, dolerite, sandstone and a central clay core.

The commonest rock type underlying the site is a red-brown mudstone that slakes rapidly and can be hand moulded when saturated. A spillway was constructed to channel water into the Sterkfontein reservoir. It consists of a baffled apron placed centrally over both sides of the dam.

Spillway discharge capacity from the Driekloof reservoir to Sterkfontein is approximately 220 m³/s. When the Sterkfontein reservoir is full and electricity generation causes the water level in the Driekloof reservoir to drop below the spillway crest, the maximum discharge from the Sterkfontein into the Driekloof reservoir is 320 m³/s.

Sterkfontein

Sterkfontein Dam is situated some kilometres from the edge of the Drakensberg escarpment. The volume of the dam wall makes it the largest earth-fill embankment dam in South Africa. It has an earth-fill embankment with an impervious core that slopes upstream. Most of the fill consists of weathered mudstone, shale and dolerite, all locally obtained. The catchment area of the reservoir is too small to require a spillway.

Mechanical aspects

The four reversible Francis sets are designed to generate a rated output of 250 MW each at 375 r/min and to pump against a maximum head of 476,7 m. These parameters qualify the machines as among the most power-ful single-stage pumped storage stations in the world as seen from the following comparative figures:

Power station	Turbine output MW (max)	Pump head m (max)	Speed r/min
Racoon (USA)	400	323	300
Imaichi (Japan)	360	573	429
Ludlington (USA)	343	114	112,5
Ohkawachi (Japan)	329	428,3	360
Dinorwig (Wales)	317	545	500
Bajina Bassa (Yugoslavia)	315	621,3	428,6
Okutatagari (Japan)	310	424	300
Tenzan (Japan)	300	548,8	400
Mingtan (Taiwan)	275	410,8	400
Drakensberg (South Africa)	270	473,5	375
Okukiyotsu (Japan)	260	512	375
Minghu (Taiwan)	257	326	300
Ohira (Japan)	256	545	400
Numappara (Japan)	230	528	375
Montezic (Western Europe)	228	426,6	429
Chaira (Bulgaria)	216	701	600
Okuyoshino (Japan)	207	539	514
Palmiet (SouthAfrica)	204	305,8	300

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.

Electrical aspects

The generator-motors 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 compen-sation. 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.

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 generation voltage of 11 kV is transformed to the national grid voltage of 400 kV. For several reasons, including security, proximity to the generators, reduction of busbar lengths and environmental considerations, the transformers and switchgear are located underground up to 86 m below the lower reservoir level. Consequently, a special cooling system is necessary. Each 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.

SF_6 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 and use the puffer-piston principle. They have a breaking capacity of 63 kA. The busbar facilitates assembly and dismantling of the circuit breakers. Lightning overvoltage protection took into consideration the length of the 400 kV feeders to the surface transmission lines. Overvoltages 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 re-quires 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 approx-imately 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.

The Drakensberg Pumped Storage Scheme operates on a weekly cycle. For a period of just over 40 hours during the weekend, Eskom experiences a low-demand period when surplus power is