Eskom Generation

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Palmiet
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.

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FORERUNNER IN ENVIRONMENTAL ENGINEERING

Cooperation for progress

For several years the Department of Water Affairs and Forestry (DWAF) conducted investigations in the Western Cape to survey possible dam sites to augment existing water supplies to the Cape Town metropolitan area. The Palmiet River basin in the Hottentots Holland Mountains not only met the requirements but also provided a potential site for a pumped storage scheme. It was clear that a venture such as this required the expertise of Eskom. Good working relationships forged over the years between the DWAF and Eskom have established close links regarding technical, administrative and financial cooperation. Consequently, developing the Palmiet Pumped Storage Scheme as a joint venture between the DWAF and Eskom was a logical step.

Eskom's participation in the scheme provides technical management and coordination expertise. The design and construction of the power station and waterways were undertaken by Eskom, whereas that of the two reservoirs, Rockview and Kogelberg, together with the connecting canal and pipeline between the Rockview and Steenbras dams, were the responsibility of the DWAF.

The contribution of the DWAF amounted to about 25% of the project's financial outlay.

In a highly successful blend of environmental management with the demands of technological progress, the Palmiet Pumped Storage Scheme has fashioned an integrated approach to engineering in South Africa. Here the old antagonism between environment and technology has been dispelled by comprehensive cooperation between protagonists on both sides.

Pumped storage schemes

Pumped storage schemes constitute a variation of the run-of-river concept normally associated with hydroelectric power stations. The power station of a pumped storage scheme is situated on the waterway which links an upper and lower reservoir. It supplies electrical energy during periods of peak demand or emergency when water is allowed to run from the upper to the lower reservoir through reversible generator-motor / pump-turbine sets. When excess generating capacity is made available by low energy demand, this same water is pumped from the lower to the upper reservoir by the reversible sets.

Using the surplus generating capacity in off-peak periods also assists in flattening the load demand curve of the system. Such generating stations can be activated in less than three minutes, whereas coal-fired stations require a minimum of eight hours to start generating power from cold start-up.

The pump-turbines used in Eskom's two pumped storage schemes at Drakensberg and Palmiet provide average generating and pumping efficiencies of over 90% and total cycle efficiencies of 73,7% at Drakensberg and 77,9% at Palmiet.

THE TAILRACE STRUCTURE IN KOGELBERG DAM

Machine No 2:	
Diameter	3,9 m tapering to 2,6 m
Length (including taper	125,0 m
to 2,6 m diameter)	
Machines 1 & 2:	
Diameter	2,6 m
Length to machine centre line	26,6 m
Power Station	
Pump-turbines	
Number of machines	2
Type of pump-turbine	Single-stage reversible Francis
Rated power output at shaft	203,5MW
per machine	
Range of net head for generation	245,5 m to 285,6 m
using 2 machines	
Range of pumping head using	264,7 m to 306,2 m
2 machines	
Maximum permissible pressure	5,39 MPa
in the penstocks	
Rated speed for both directions	300 r/min
of rotation	
Method of pump starting	Static frequency converter
Type of control	Local and remote
Generator-motors	
Continuous rating of each	200 MW at terminals at
machine for generation	0,8 power factor
Rated voltage	16,5 kV
Rated MVA	250,00 MVA
Rated current	8 748 ampere
Power factor pumping /	0,8
generating	
Rated frequency	50 Hz
Rated output of starter (SFC)	21,6 MW
Speed	300 r/min
Transient runaway speed	497 r/min
Inertia GD2	9,7 x 106 kg/m^2
Excitation	Static feed from machine terminals
Tailrace tunnels	
Number	2
Internal diameter	5 m
Length – sets 1& 2	83,6 m and 57 m respectively
Type of construction	Concrete lined

Operating data	
Generation energy equivalent	Approximately 10 GWh
to 15 million m^3	
Time required to pump	Approximately 40 hours
15 million m^3 of water from	
lower to upper reservoir	
Type of operational cycle	Weekly
Cycle efficiency	77,9%
Construction / Commissioning	
Commencement of	November 1983
construction	
Commissioning	May 1988
Major consultants	
Civil engineering	
Civil consulting engineers	SVE (a consortium of companies
	consisting of Ninham Shand,
	Van Niekerk, Klein & Edwards,
	and Electrowatt)
Environmental consultants	Ecokonsult Incorporated
Major contractors	
Exploratory excavation	Department of Water Affairs
Preliminary civil work	Savage & Lovemore (Pty) Ltd
Main civil work	Palmiet Civil Contractors
Rockview & Kogelberg dams	Department of Water Affairs
Mechanical engineering	
Pump-turbines, governors	
and spherical valves	JM Voith GmbH West Germany
Penstock steel linings	Sorefame Africa (Pty) Ltd
Gates and screens	John Thompson Africa (Pty) Ltd
Machine hall crane	Mannesmann Demag (Pty) Ltd
Low-pressure service pipe-work	Steel Metals
Electrical engineering	
Generator-motors	Fuji Electric Co Japan
Transformers	ASEA Electric (SA) Ltd
Load switches and	Brown Boveri (SA) (Pty) Ltd
reversing isolators	
Control room equipment	Siemens

TECHNICAL DATA

Upper reservoir (Rockview Dam)		Maximum dam height	57 m
Type:		above river bed	
Main embankment	Rockfill	Length of concrete wall crest	186 m
Northern embankment	Sandfill		
		Headrace tunnel	
Height above lowest foundation:		Number	1
Main embankment	50 m	Internal diameter	6,2 m
Northern embankment	35 m	Length	739,4 m
		Type of construction	Steel lined
Length of crest:			
Main embankment	1 250 m	**Surge tank**	
Northern embankment	700 m	Number	1
		Type	Cylindrical, free-standing structure
Volume content of dam wall:		Internal diameter	21 m
Main embankment	3,1 million m^3	Height	61 m
Northern embankment	0,43 million m^3	Orifice diameter	4,2 m
Full supply level	531 masl	Construction	Post-stressed concrete
Lowest operational level for	504 masl		
two machines generating		**Inclined pressure shaft**	
Minimum level	501 masl	Number	1
Gross storage capacity	20,8 million m^3	Length	122,7 m
Active storage capacity	17,0 million m^3	Diameter	6,2 m
Surface area at full supply level	73,4 ha	Type of construction	Steel lined
		Angle of horizontal plane	55°
Capacity:			
Canal / pipeline into	12 m^3/s	**Pressure tunnel**	
Steenbras Dam		Number	1
Spillway	None	Diameter	6,2 m
		Length (including taper	494 m
Lower reservoir (Kogelberg Dam)		to 5,4 m diameter)	
Type:	Mass concrete gravity arch wall with	Type of construction	Steel lined
	separate earth saddle embankment	Inclination	1:10
Volume content of	70 000 m^3		
concrete dam wall		**Penstock**	
Volume content of	220 000 m^3	Number	1 (bifurcating)
earth embankment		Length of bifurcation	561,2 m
Non-overflow crest	252 masl	Diameter	5,4 m
Full supply level	246 masl	Type of construction	Buried in trench
Lowest operational level for	230 masl	Inclination	1:10, 1:6 and 1:15
two machines generating			
Minimum level	228 masl	**Branches of penstock**	
Gross storage capacity	19,3 million m^3	Number	2
Active storage capacity	15,0 million m^3	Machine No 1:	
Surface area at full supply level	155,4 ha	Diameter	3,9 m tapering to 2,6 m
Capacity of spillway	1 060 m^3/s	Length (including taper	134,8 m
Type of spillway	Ogee	to 2,6 m diameter)	

The Palmiet Pumped Storage Scheme

The Palmiet Pumped Storage Scheme is situated in one of the spurs of the Hottentots Holland Mountains where the potential of the fluvial system is virtually untapped. The catchment area of the Palmiet River could in fact supply sufficient water for four more dams in addition to Kogelberg. Palmiet acts not only as a hydroelectric pumped storage scheme, but also as a water transfer scheme.

The scheme comprises two dams, the lower Kogelberg Dam on the Palmiet River south of Grabouw and the upper Rockview Dam on the watershed between the Palmiet and Steenbras rivers. A conduit between the two reservoirs conveys water to the reversible pump-turbines in the 400 MW station on the bank of the Kogelberg reservoir. During the off-peak period, water is pumped from Kogelberg to Rockview reservoir. From here water specifically allocated to the DWAF for water supply flows by gravity into the Steenbras reservoir via a separate conduit. This supplements the annual water supply of Cape Town by an average of 25 million cubic metres.

The power generated at the Palmiet Pumped Storage Scheme is fed into the national transmission network at the Bacchus substation near Worcester. A special feature of the high-voltage yard at Palmiet is the tubular, low-level, high-voltage busbar, which is used to minimise visual impact.

The power station and waterways

The power station is situated about 2 km upstream of the Kogelberg Dam wall and has a nominal generating capacity of 400 MW. The two 200 MW generator-motor/pump-turbine sets and auxiliary equipment are located approximately 60 m below ground level at the base of two 23 m diameter, concrete-lined, vertical machine shafts.

The auxiliary equipment includes the pump-turbine governor and spherical valve with their respective oil pressure units, the CW pumps, water depression air tank and the unit transformer and unit board.

At a depth of 80 m, a set of dewatering and drainage pumps is located in a 5 m diameter service shaft between the machine shafts. The surface machine hall houses a huge crane with a lifting capacity of 360 tons, span of 30 m and hoisting height of 65 m.

The control room is situated 5,5 m below the machine hall floor. Adjoining surface buildings house the switchgear, air-conditioning plant, starter, blow-down compressors and offices.

In the generating mode, up to 185 m^3/s of water is admitted at the intake from the upper reservoir (Rockview Dam) through a surface cut-and-cover headrace tunnel, 750 m long and 6,2 m in diameter. It flows through a 55° inclined shaft, 130 m deep and 6,2 m in diameter, to a pressure tunnel, 487 m long and 6,2 m in diameter, which ends at a portal. From here water flows into a cut-and-cover penstock, 561 m long and 5,4 m in diameter, which bifurcates into two inclined penstock shafts, approximately 131 m and 139 m long respectively and 3,9 m in diameter, tapering to 2,6 m in diameter. The penstocks convey the water into the power station complex.

From the power station, two inclined concrete-lined tailrace tunnels, 84 m and 57 m long respectively, link the machines to the tailworks in the Kogelberg reservoir.

The surge tank is situated at the end of the surface cut-and-cover headrace tunnel. A 34 m long conduit, 6,2 m in diameter, branches from the headrace tunnel to lead to the bottom of the surge tank. The cylindrical, free-standing concrete structure of the surge tank is 61 m high and 21 m in diameter. To minimise visual pollution the surge tank was not constructed on the highest point of the terrain, but set back from the cliff so that it is less prominent to viewers from the Palmiet River area. The surge tank prevents excessive pressure fluctuations in the penstock during transient conditions.

From the Rockview Dam wall, an access bridge leads to the headrace works, constructed in the form of a 68 m high headworks tower. This tower houses the 15 m wide, 14 m high screened intake, the mechanically operated maintenance stop logs and the hydraulically operated emergency gate.

Within the headrace tower is a vertical duct with a spillway on top, which makes it possible to close the emergency gate during any phase of surging in the waterways. This is a unique safety feature designed by Eskom engineers. The duct houses the emergency gate, provides for the discharge of the surplus volume of water during emergency closure and allows aeration of the headrace tunnel after closure of the gate.

The outlet works on the bank of the lower reservoir consist of twin 45 m high tailworks towers next to the power station. Each tower houses an 8,7 m wide and 9,5 m high screened opening, a mechanically operated wheeled maintenance gate and a submersible pump which supplies the fire-fighting storage tank.

The power station operates on a weekly cycle. Power is generated at peak periods from Monday to Friday. The water used for generation is only partially pumped back from the lower Kogelberg to the upper Rockview reservoir every day. Consequently, the level of the water in the Rockview reservoir is gradually lowered during the week. Over weekends, when system demand is low, water is pumped back from the Kogelberg into the Rockview reservoir at an average rate of approximately 126 m^3/s over a period of about 40 hours to restore the reservoir to full capacity.

The reservoirs

The upper reservoir – Rockview Dam

The upper reservoir has virtually no natural catchment area as it is situated on the watershed between the Palmiet and Steenbras rivers. Its basin is formed by a rockfill and an earthfill wall known respectively as the main and northern embankment. The waterways lead from the main embankment to the power station. From the northern embankment, a canal and a pipeline connect the Rockview reservoir to the upper reservoir of the Steenbras Scheme. Water transfer to augment water supplies takes place along this route.

The main embankment

This is a 3 100 000 m^3 rockfill dam, constructed of material from the basin of the reservoir itself. It consists of a 556 000 m^3 clay core seal, with rockfill sides for stability, and an additional 206 000 m^3 of filter materials which provide a buffer zone between the clay and the rockfill. A layer of high-quality rockfill protects the embankment against the wave action of the water. It has a crest length of 1 250 m.

Restoration undertaken concurrently with construction rather than on completion of the projects is considerably cheaper. This approach has also heightened individual perception of the need for environmental management and has encouraged greater understanding in the engineering profession of the importance of a carefully planned and monitored interaction with the environment. The fusion of both engineering and environmental principles and objectives created a unity of action and purpose which produced an improved quality of life for all concerned, both during and after construction.

Unique aspects of the environmental impact control programme

The Palmiet Pumped Storage Scheme is largely situated within the Kogelberg Nature Reserve, which was established as a conservation area for mountain and riverine fynbos.

Propagation of certain fynbos species depends on the feeding habits of the indigenous porter ants. By taking a seed underground and eating the gland but leaving the kernel, they enable the seed to germinate. Extensive measures were adopted to prevent the introduction of the exotic Argentinian ant which could possibly exterminate the local ants as well as contribute to the destruction of the fynbos by leaving the seeds exposed to fire and the elements.

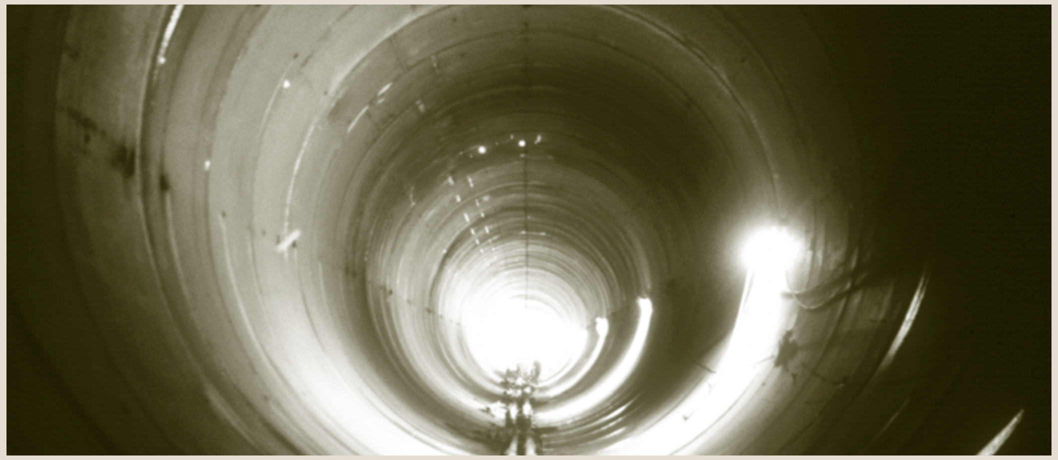
Consequently, specific eating sites were delineated and the removal of all rubbish and waste strictly controlled. Construction materials were carefully inspected to eliminate the possible introduction of non-indigenous plants and insects. Topsoil, which generally contains the valuable fynbos seed, was removed and conserved to be replaced in specific areas once construction was completed. Fynbos was re-established along the side of roads. Disturbance of fauna and flora remains prohibited.

Kogelberg Biosphere Reserve

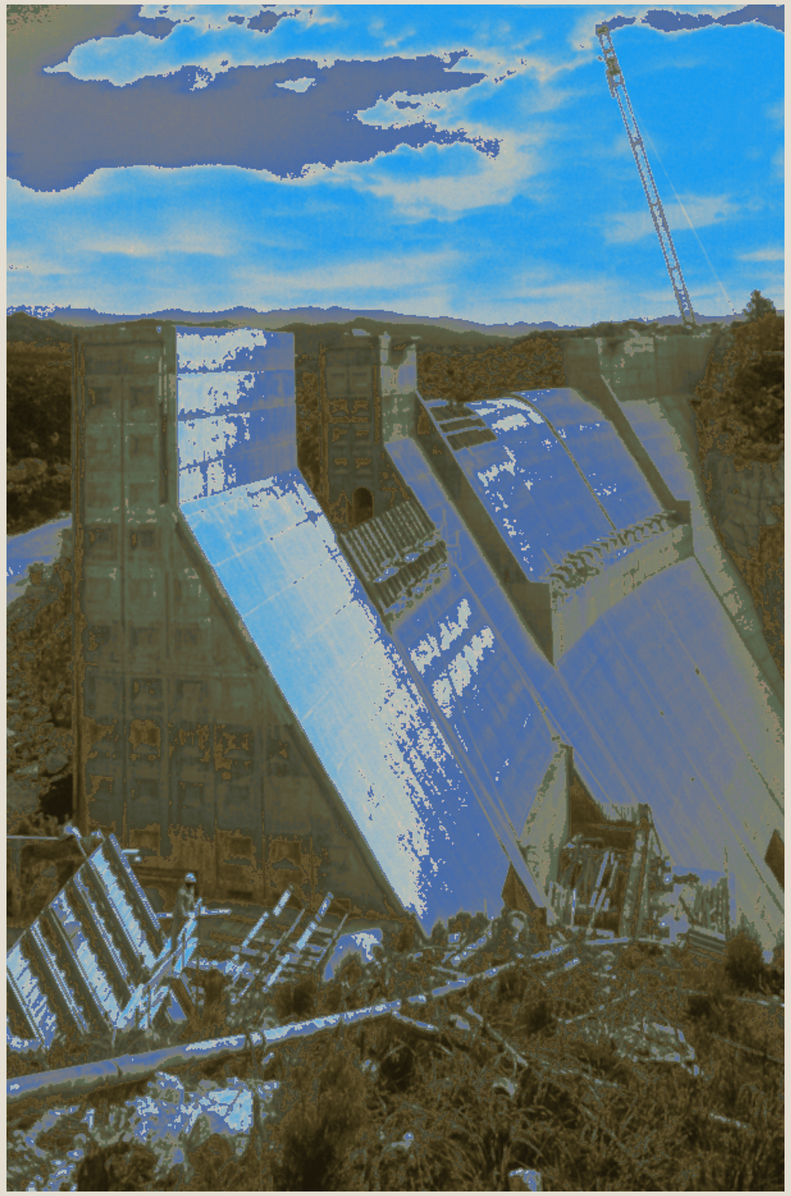
The Kogelberg Biosphere Reserve (KBR) was the first of its kind in South Africa and was designated as such by UNESCO's Man and the Biosphere Programme (MAB) in December 1998. Eskom was a signatory to the application for biosphere status, which aimed to integrate conservation of biodiversity and the sustainable utilisation of natural resources.

A Declaration of Commitment was signed in 1998 acknowledging Eskom's undertaking to pursue the objectives identified in the UNESCO Action Plan for Biosphere Reserves as identified in the Seville Strategy.

The Kogelberg Nature Reserve, in the heart of the Cape Fynbos Plant Kingdom, is part of the Kogelberg Biosphere Reserve, which comprises the entire coastal area from Gordon's Bay to the Bot River vlei and inland to Grabouw and the Groenland Mountain – approximately 92 000 ha.



A SECTION OF THE 6,2 m DIAMETER STEEL LINED WATERWAY were mandatory. The RECO enjoyed arbitration to the highest levels of authority. Workers at all levels were individually involved by means of educational audiovisuals in English, Afrikaans and Xhosa and their participation was encouraged by the award of an Environmental Floating Trophy for excellence in environmental impact control.



CONSTRUCTION OF THE KOGELBERG DAM WALL

In addition to these considerations, the visual impact of the scheme was evaluated and action taken to minimise pollution. Access roads were routed to avoid scenic outcrops of rock or sensitive plant growth areas and to follow natural contours, thus blending in with the landscape. The Palmiet Power Station, as well as the waterway linking the Rockview and the Kogelberg dams, was placed underground and indigenous plants were reestablished on the disturbed site. Quarrying of construction materials from the Rockview basin was restricted to a specific height below the full supply level.

Water pollution from cementing, drilling, grouting and general activity on the site was eliminated by allowing sedimentation in special settling tanks before the water was returned to the river.

The main approach of the environmental impact control programme was preventive rather than curative. From a purely economic aspect the benefits of this preventive approach have been tangible and savings of as much as 1,5% of the project cost were calculated.

The northern embankment

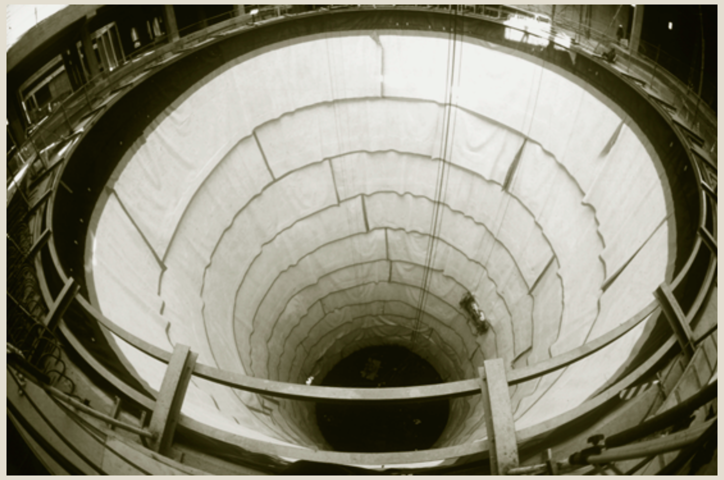
The northern embankment is a 150 000 m³ sandfill wall containing a 102 000 m³ clay core with an additional 33 000 m³ of filter materials. A rockfill blanket protects the sand from erosion by wind and wave. Since there was insufficient sandfill available to construct the whole dam, it was completed with approximately 146 000 m³ of rockfill. The crest length of the northern embankment is 700 m.

Waterways to the upper reservoir of the Steenbras Scheme

The waterways to the upper reservoir of the Steenbras Pumped Storage Scheme begin as a low-gradient concrete-lined trapezoidal canal, 1,80 km long, which leads into a small forebay. From here a 2,0 km long steel penstock with a maximum discharge capacity of 12 m³/s channels water into the Steenbras reservoir. From this upper reservoir, water is supplied to the City of Cape Town (CMC) municipality via the existing Steenbras Pumped Storage Scheme owned and operated by the Cape Town Administration.

Borrow pits

Sand and rockfill for the construction of the embankments were obtained from the reservoir basin. Clay for the core of the dams was brought in from a borrow pit adjoining the upper reservoir of the Steenbras Scheme. This borrow pit has been covered with topsoil, reshaped to blend with the terrain and planted with pine trees.



THE SHAFTS ARE LINED WITH A WATERPROOF MEMBRANE

The lower reservoir – Kogelberg Dam

The Kogelberg Dam is designed with a mass concrete gravity arch wall. It has a separate earth saddle embankment on the left flank about 850 m long at a maximum height of 19 m.

The concrete wall

The concrete wall has a gravity section arch configuration and an ogee overflow with a concrete apron beneath to protect the riverbed from erosion. River outlets are provided to allow compensating water to flow into the river downstream of the dam. All material for the construction was obtained from the Rockview reservoir basin.

The earth embankment

The earth embankment is a saddle wall which dams the low-lying area adjacent to the concrete wall. The clay core, built of material from a nearby borrow pit, has a volume of 35 000 m³. The flanks consist of 146 000 m³ of semi-pervious material drawn from the dam basin and a further 15 000 m³ of filter materials. A 24 000 m³ layer of rip-rap protects the embankment from wave action.

Preliminary site investigation

Eskom and the Department of Water Affairs and Forestry commenced exploratory site investigations three years before any contracts were awarded. This included the sinking of a shaft, 65 m deep by 6 m in diameter, near the proposed machine shafts, and the excavation of a 250 m long adit parallel to the main tunnel. These works permitted the investigation and analysis of significant features of the folded geology such as jointing and cross-bedding, from which areas of possible rock instability could be established. Ground water conditions and the presence of phyllite-filled joints were determined and monitored. Detailed information on the geological structures, including rock formations and underground waterways and shafts, was incorporated into a geological / geotechnical report issued as part of the tender documents for the civil contracts. As a result, a very accurate assessment of contractual risk could be made by the tenderers.

Electrical features of the system

The generator-motors are directly coupled to the pump-turbines and are designed to operate in three modes:

1. The generating mode – potential energy is converted into electrical energy.
2. The pumping mode – off-peak low-cost electrical energy is converted into potential energy by pumping water from the lower to the upper reservoir.
3. The synchronous condenser mode – reactive power is either sent out or absorbed by the machine to control the voltage on the transmission system.

The generator-motors produce power at 16,5 kV, which is then stepped up to 400 kV by generator transformers installed in the transformer yard adjacent to the station.

The rotating plant is designed in such a way that it may be started and synchronised even when connected to a blacked-out network. Normally, lack of power would prevent the operation of the auxiliary plant necessary for the safe running of the unit. An accumulator system installed for the Palmiet units injects previously stored high-pressure oil into the thrust bearings to ensure the safe starting of the machine. Run-up is achieved by opening the guide vanes by means of previously stored hydraulic pressure. This allows water into the turbine. Once rotating, the generator builds up voltage by "field flashing" from the station batteries and, when excited to full voltage, is capable of supplying all its own auxiliaries from its generated output.

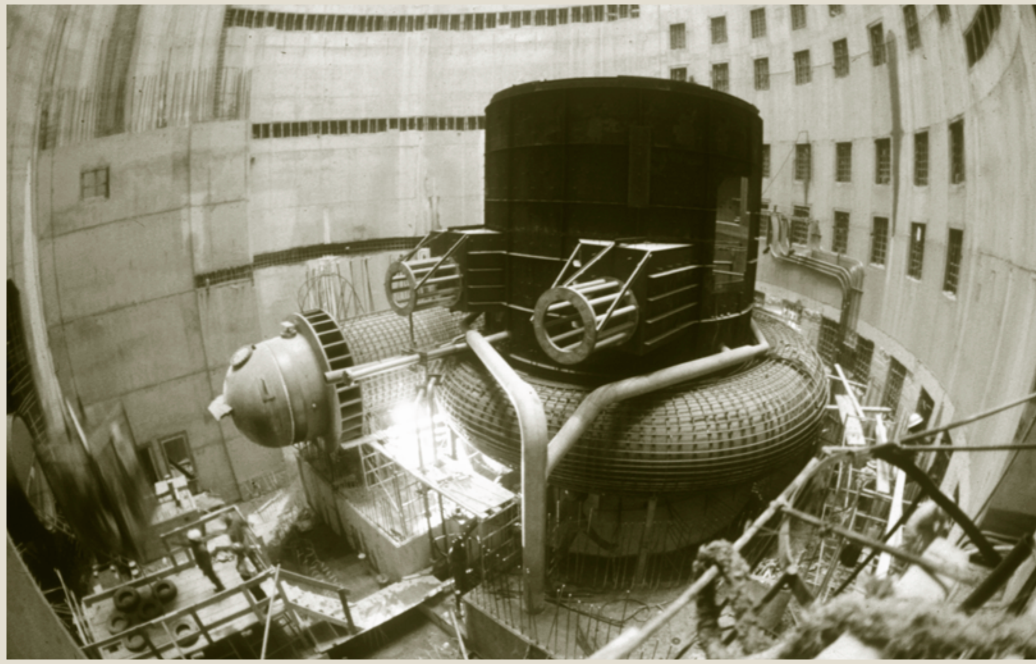
The units are fitted with a magnetic thrust bearing which decreases the load by means of a magnetic field thus reducing bearing friction losses. The bearings themselves are self-lubricating (except during actual start-up). This eliminates the need for oil pumps and associated piping. These measures reduce the cost of unit auxiliaries and increase plant efficiency.

When the pump-turbine operates as a pump, the generator-motor assumes a motoring condition. When starting the pumps, the high inertia of the rotor makes it impossible to switch the generator-motor directly on to the transmission system without causing excessive voltage dips. A static frequency convertor (SFC) is used to achieve a "soft" start of the motor. Converting the 50 Hz mains frequency to much lower frequencies (0 up to 50 Hz), it increases the generator-motor speed gradually to avoid the voltage dips caused by sudden excessive current demand. Furthermore, before rotation of the machine as a pump is started, air is blown into the pump-turbine to reduce the run-up current to a minimum.

In the unlikely event that the SFC is not available it is possible to start one unit back to back with the other, with one generator-motor operating as a generator while the other operates as a motor. The two machines then run up together.

Low-level tubular busbars are used in the high-voltage yard instead of high-voltage connecting cables, thus minimising the visual environmental impact.

The generator-motors are phase-reversed and connected to the generator transformer through 5 x 16,5 kV isolators and a 16,5 kV load switch. The load switch utilises SF6 technology, thus making more effective use of space.



THE SPIRAL CASING DELIVERS WATER TO THE TURBINE RUNNER

The Palmiet Pumped Storage Scheme is used for supplying peak power as well as for system frequency control, system voltage control and emergency standby. The machines have been designed to cope with high-fatigue stresses resulting from the frequent mode changes (up to 600) anticipated in their monthly operations.

Fusion of nature and progress

Palmiet is situated in an ecologically sensitive area of the Western Cape. From the outset, a firm of environmental consultants was appointed to assess the impact of the scheme on every aspect of the natural and human environment. A comprehensive programme of control, protection and restoration was established which, in a unique move, was written into the civil engineering contract. A resident environmental control officer (RECO) was appointed to monitor the implementation of the Environmental Impact Control Plan, liaising with and advising construction teams.

In South Africa today, umbrella legislation on environmental protection provides measures to compel developers to minimise the negative impact of their undertakings on both natural and man-made environments. No such legislation existed at the time of construction. Cooperation between industrialists, engineers and environmentalists arose from a mutual desire to achieve the best possible balance between technological progress and environmental management.

Certain aspects of environmental management, introduced during the construction of Eskom's first pumped storage scheme at Drakensberg, had a profound influence on Eskom's approach to the Palmiet project. The Palmiet Pumped Storage Scheme is one of the major engineering undertakings in South Africa that has seen a total integration of both environmental and technical principles with the willing cooperation of all participants.

From the inception of the scheme, constructors and engineers recognised the importance of environmental protection and restoration. They welcomed and encouraged a new approach to construction by accepting and enforcing environmental impact control requirements in the civil engineering contract. All civil design deviations were first submitted to the officially appointed environmental consultant and the RECO who assessed their impact on the environment and formulated control measures that